COMPARATIVE ANALYSIS BETWEEN SINGLE SCREW EXTRUSION (*SSE*) & TWIN SCREW EXTRUSION (*TSE*)
BASICS OF SSE TECHNOLOGY

- **Screw design** = single piece (constant pitch, decreasing channel depth) or a splined shaft that holds screw sections of varying configuration (pitch)

- **ONE SINGLE PROCESSING SECTION** (pressure buildup section behind the die)

*SSE = Single Screw Extruder*
BASIC INFORMATION ON SSE TECHNOLOGY

SCREW DESIGN
Single piece (constant pitch, decreasing channel depth) or a slotted shaft and screw sections with different configurations (steps)

ONLY ONE PROCES SECTION
Pressure accumulation section behind the matrix

PRECONDITIONER
Raw mix

P

Axial distance, z
BASICS OF SSE TECHNOLOGY
Flow characteristics in the screw channel

Drag flow
Pressure flow

Velocity profiles in the screw channel

Down channel direction
BASICS OF SSE TECHNOLOGY

Flow characteristics in the screw channel

- The forward pitch of the screw flight conveys the materials down the channel by developing a « DRAG FLOW », which velocity is directly proportional to the screw speed N.

- Because of the die restriction at the extruder’s discharge, there is a « PRESSURE FLOW », which is opposite in direction to the drag flow.

Thus SSE Flow rate = Drag flow rate – Pressure flow rate

\[ Q = \alpha N - \beta \left( \frac{dP}{d\mu_a} \right) \]

Operational flow rate is dictated by N, die pressure and melt rheological properties: the coupling of these variables limits the operating range and flexibility of SSEs.
BASICS OF SSE TECHNOLOGY
Main process characteristics

✓ SSE Technology = ONE SINGLE PROCESSING SECTION.

✓ In SSE, throughput is directly proportional to SCREW SPEED. Then, for a given feed mix, SSE is characterized by ONE SINGLE OPERATING POINT, that is: throughput combined with max. screw speed and die opening area.
Fluid dynamics in the screw channel shows that fluid particles have different velocities and do not interact, which leads to a dispersion of residence times and poor mixing.

Consequently, heat transfer as well as mechanical energy input in the cooking section are very limited. Besides, the extent of shear is space-dependent, which leads to generate heterogeneities of melt properties (cooking extent, temperature, strain, in particular).
BASICS OF SSE TECHNOLOGY
Main process characteristics

- SSE Technology = ONE SINGLE PROCESSING SECTION.
- SSE Technology = dependency of THROUGHPUT and SCREW SPEED.
- SSE Technology = ONE SINGLE OPERATING POINT (throughput combined with max. screw speed and die opening area).

- In SSE, MIXING IS VERY POOR, which limits heat transfer, mechanical energy input, and generates heterogeneities of melt properties (cooking extent, composition, temperature, strain…).
When the flight clearance $\delta$ increases, or the screw wear increases, LEAKAGE FLOW is generated which leads to invariably decrease the extruder throughput:

$$Q = \alpha N(1 - \delta/H) - \left( \frac{\beta}{\mu_a} \frac{dP}{dz} \right) (1 + f)$$

where $\delta/H \gg$ fat small flight clearance
In SSE, perfect melt adherence at the barrel wall is required to obtain the maximum throughput of the extruder. Any change in the melt composition which generates MELT SLIP at the barrel wall would lead to dramatic decrease of the extruder throughput.

In feed extrusion processing, « SLIP INDUCERS » are: moisture, meat slurries, protein hydrolysates, fat, for instance.

Melt slip at the barrel wall decreases importantly the extent of mixing as well as the heat transfer and shear rate (mechanical energy input).
BASICS OF SSE TECHNOLOGY
Main process characteristics

✓ SSE Technology = ONE SINGLE PROCESSING SECTION.

✓ SSE Technology = dependency of THROUGHPUT and SCREW SPEED.
SSE Technology = ONE SINGLE OPERATING POINT (throughput combined with max. screw speed and die opening area).

✓ SSE Technology = VERY POOR MIXING, which limits heat transfer, mechanical energy input, and generates heterogeneities of melt properties (cooking extent, composition, temperature, strain…).

✓ SSE Technology = as screw wear increases, EXTRUDER THROUGHPUT DECREASES. A decrease of 10-20% may be observed over the lifetime of the screw.
SSE Technology = « slip inducers » in the melt composition generate SLIP, which decreases the EXTRUDER THROUGHPUT, as well as the extent of MIXING and MECHANICAL ENERGY INPUT.
BASICS OF SSE TECHNOLOGY
Process limitations

- Range of raw materials restricted: It processes tight specifications (particle size, biochemical composition)
- Low tolerance to lipids in raw material
- Low tolerance to moisture variations in raw materials
- Low flexibility in thermomechanical cooking: Screw profile, operating variables, energy input
- Low consistency of product quality
INTERMESHING SCREWS IN TSE

COUNTERTOROTATING

FLOW

COROTATING

FLOW
Corotating TSE has MULTIPLE FILLED PROCESSING SECTIONS IN SERIES, (melting/cooking, degassing, positive pumping…), thanks to screw restrictions used to back-fill TSE. Processing sections show high level of mixing, heat transfer and shear (mechanical energy input).
Corotating TSE is a **POSITIVE DISPLACEMENT PUMP**, thanks to the interpenetration of the screws. This allows to handle viscous, oily, sticky or very wet materials, with the same level of pumping efficiency.

Contrary to SSE, the throughput of corotating TSE is, within the limits of reasonable operation, **INDEPENDENT OF DIE PRESSURE**.
BASICS OF COROTATING TSE

Flow characteristics in the screw channel

As in SSE, TSE flow rate is composed of a drag flow and a pressure flow. But, flow rate and screw speed operate independently in a large range of operating, thanks to the variation of the length of fully filled sections.

EFFECT OF PROCESS PARAMETERS ON PRESSURE BUILDUP AND LENGTH OF FILLED SECTIONS

- Increase of throughput
- Increase of screw speed
- Increase of flow restrictions
BASICS OF COROTATING TSE
Main process characteristics

✓ Corotating TSE Technology = MULTIPLE FILLED PROCESSING SECTIONS IN SERIES.

✓ In corotating TSE, THROUGHPUT AND SCREW SPEED are decoupled.

Then, for a given formulated feed mix, corotating TSE is characterized by MULTIPLE OPERATING POINTS. Besides, SCREW PROFILE can vary extensively to modulate the mechanical energy input.
In corotating TSE, **VERY INTENSE MIXING** is observed in the intermeshing zone of the screws (macromixing, micromixing).

Consequently, heat transfer coefficient in the fully filled sections is high. Homogeneous melts can be obtained, with very good lipid binding. Die expansion develops consistently, which leads to give consistent product density, texture and shaping as well as uniform final product color.
BASICS OF COROTATING TSE
Main process characteristics

✓ Corotating TSE Technology = MULTIPLE FILLED PROCESSING SECTIONS IN SERIES.

✓ In corotating TSE, THROUGHPUT AND SCREW SPEED are decoupled. Then, for a given formulated feed mix, corotating TSE is characterized by MULTIPLE OPERATING POINTS. Besides, SCREW PROFILE can vary extensively to modulate the mechanical energy input.

✓ In corotating TSE, MIXING IS VERY INTENSE which gives tremendous benefits in regards to product quality.
In corotating TSE, wear occurs at the restrictions and preceding screw elements. By varying the screw speed, it is possible to maintain the throughput, the mechanical energy input, and product quality over the lifetime of the screws.

In corotating TSE, melt slipping does not affect the throughput, thanks to positive pumping of the screws: one screw sweeps out the channel of the other screw, and vice versa.
BASICS OF COROTATING TSE
Main process characteristics

✓ Corotating TSE Technology =
MULTIPLE FILLED PROCESSING SECTIONS IN SERIES.

✓ In corotating TSE, **throughput and screw speed** are decoupled.
Then, for a given formulated feed mix, corotating TSE is characterized by
**multiple operating points**. Besides, **screw profile** can vary extensively to
modulate the mechanical energy input.

✓ In corotating TSE, **mixing is very intense** which gives tremendous
benefits in regards to product quality.

✓ Corotating TSE Technology = **wear development** compensated by **screw
speed** increase.
Corotating TSE Technology = **melt slip** compensated by **positive pumping
of the screws**.
SSE VERSUS TSE
determinant advantages of TSE thanks to micromixing

- More uniform Viscous Dissipation
- Higher process Flexibility
- Higher Heat Transfer Coefficient
- Lower sensitivity to Product constraints
- Higher tolerance to Fat content
- Better control of Energy Inputs
- Lower sensitivity to Raw Mat. changes
- Higher tolerance to Moisture changes
- Better Quality of End-Products
- Better consistency of End-Products
SSE VERSUS TSE IN PRACTICE
Pet-Food example

% TOTAL FAT

SINGLE SCREW EXTRUDER

CLEXTRAL TWIN SCREW EXTRUDER

% TOTAL MEAT or SLURRY

PRODUCT B. DENSITY RANGE (gr/l)
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