stamixco

Static Mixing Technology
For
Extrusion and Injection Molding

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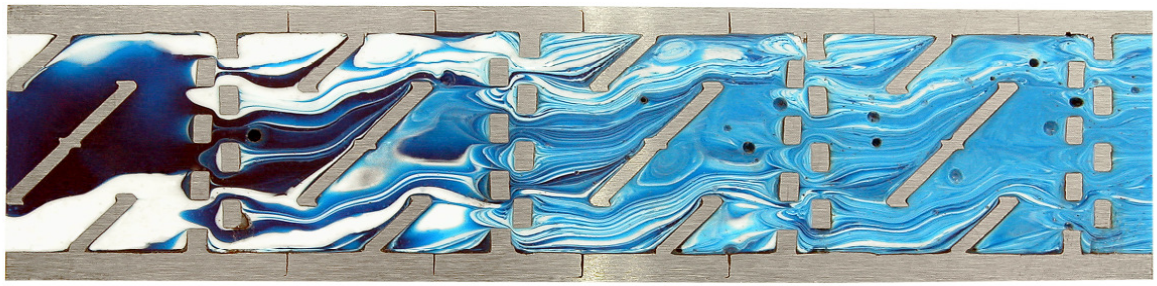


Content

- Introduction
- Static mixer for melt homogenization
  - Working principle, mixing performance of different types of static mixers
  - Pressure drop, power requirement
  - Installation, benefits
- Homogenization of polymer melts regarding uniform distribution of
  - Concentration of colorants, additives
  - Temperature
- Plug-flow behaviour, self cleaning
- Conclusions

Process Requirement for Quality Products?

→ A perfectly homogeneous melt at the inlet to the die/mold

Reality

- Melt homogeneity often inadequate regarding:

  - distribution of concentration (colorants, additives, blowing agents)
    → colorant streaks, clouds, irregular cell sizes

  - uniformity of temperature distribution
    → viscosity differences
      → e.g. wall thickness variation, distortion, irregular cell sizes

Reasons for Inhomogeneous Melts

The screw has many different functions

→ it's an "all in one" equipment
→ design calls for compromises to fulfill all functions

- drawing-in of material (granulate, powder)
- compacting the solids
- melting/plasticizing the polymer
- homogenizing the melt (mechanically/thermally)
- discharging the melt
- additional mixing requirements when adding colorants, additives, blowing agent
  → problem: admixing of small additive ammounts, viscosity difference

Injection molding:

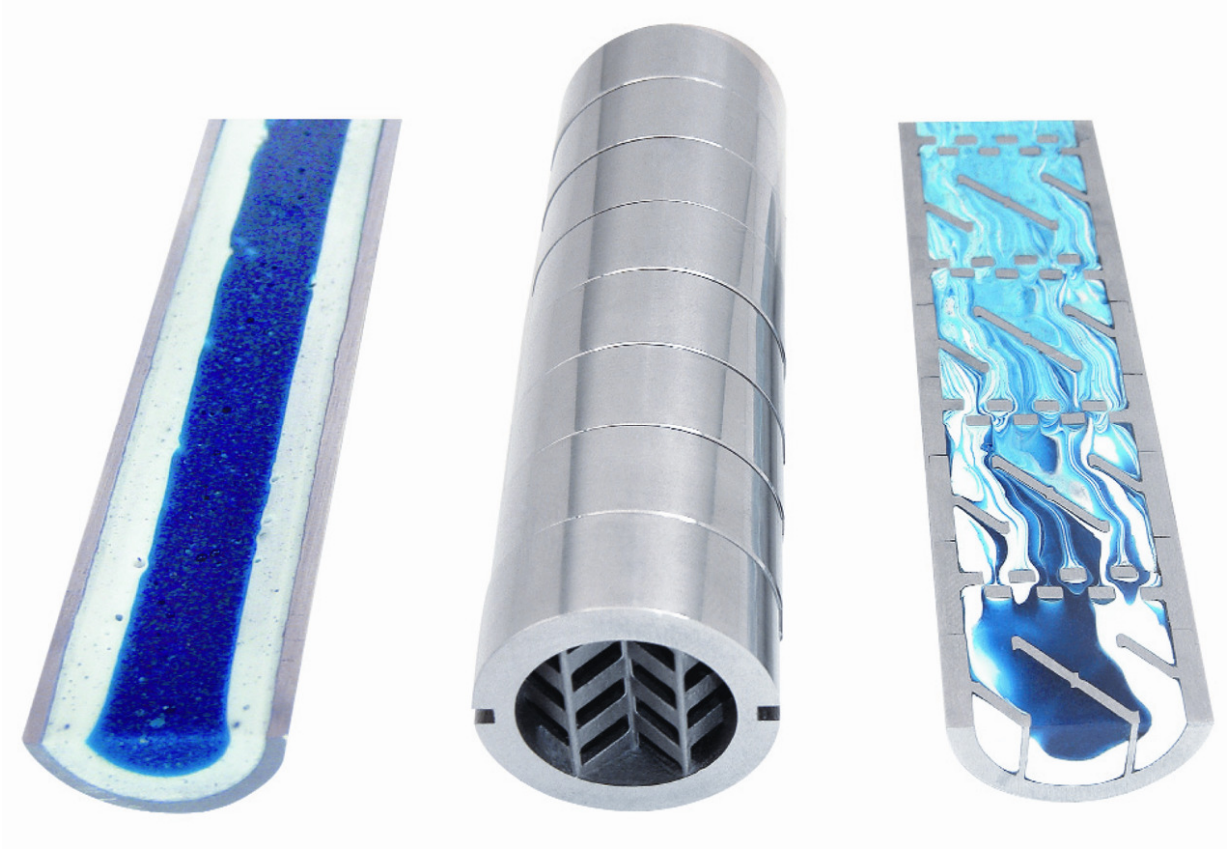
- short screws, reducing active length during plasticizing

Possible Solution to improve the Melt Homogeneity

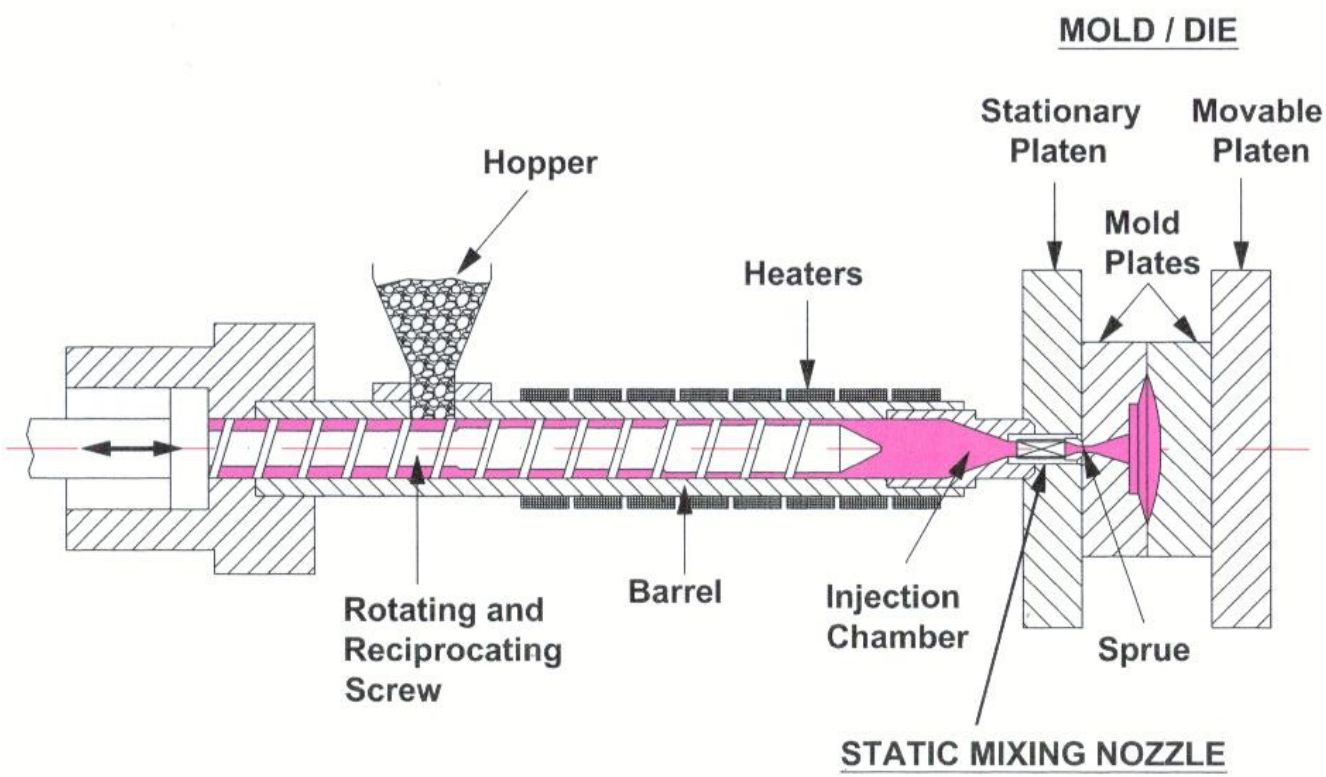
Static Mixer

installed between
Barrel and Gate of Mold / Die

Static Mixers Homogenize Polymer Melts with no Moving Parts

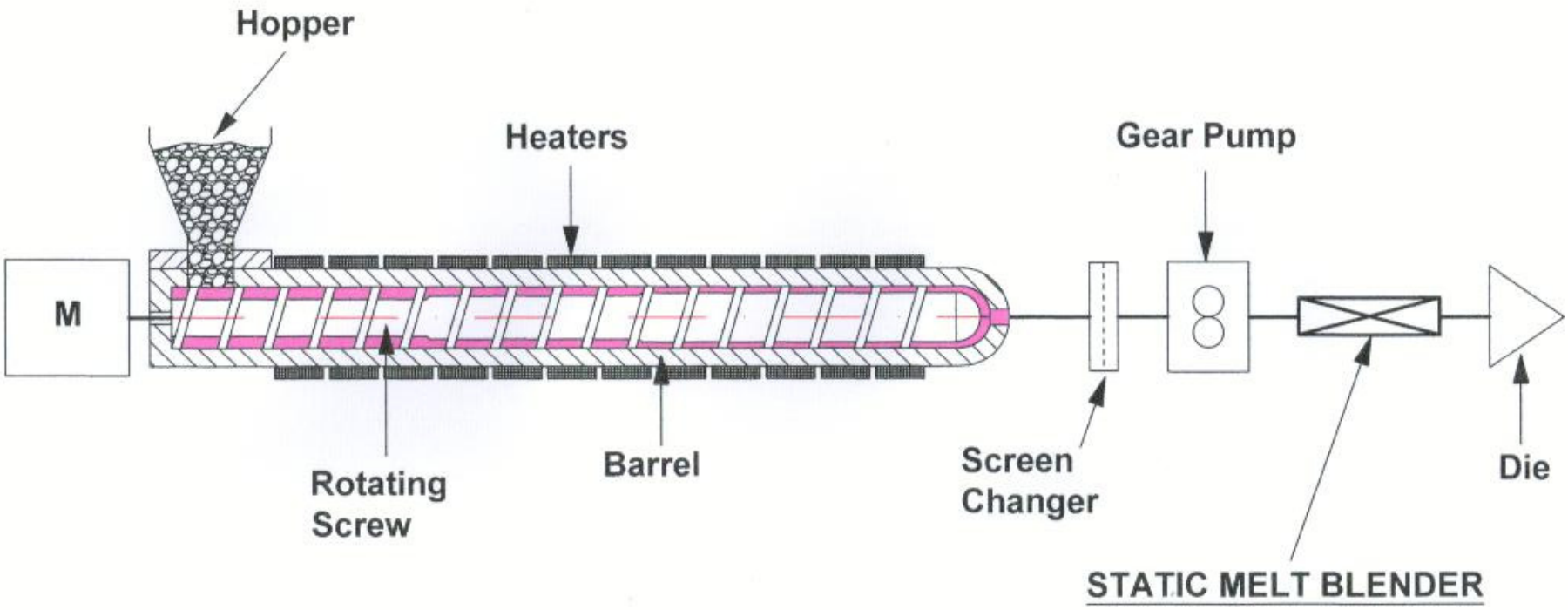


Where are Static Mixers Installed on Injection Molding Machines?



Injection Molding Mixing Nozzle

Where are Static Mixers Installed on Extruders?

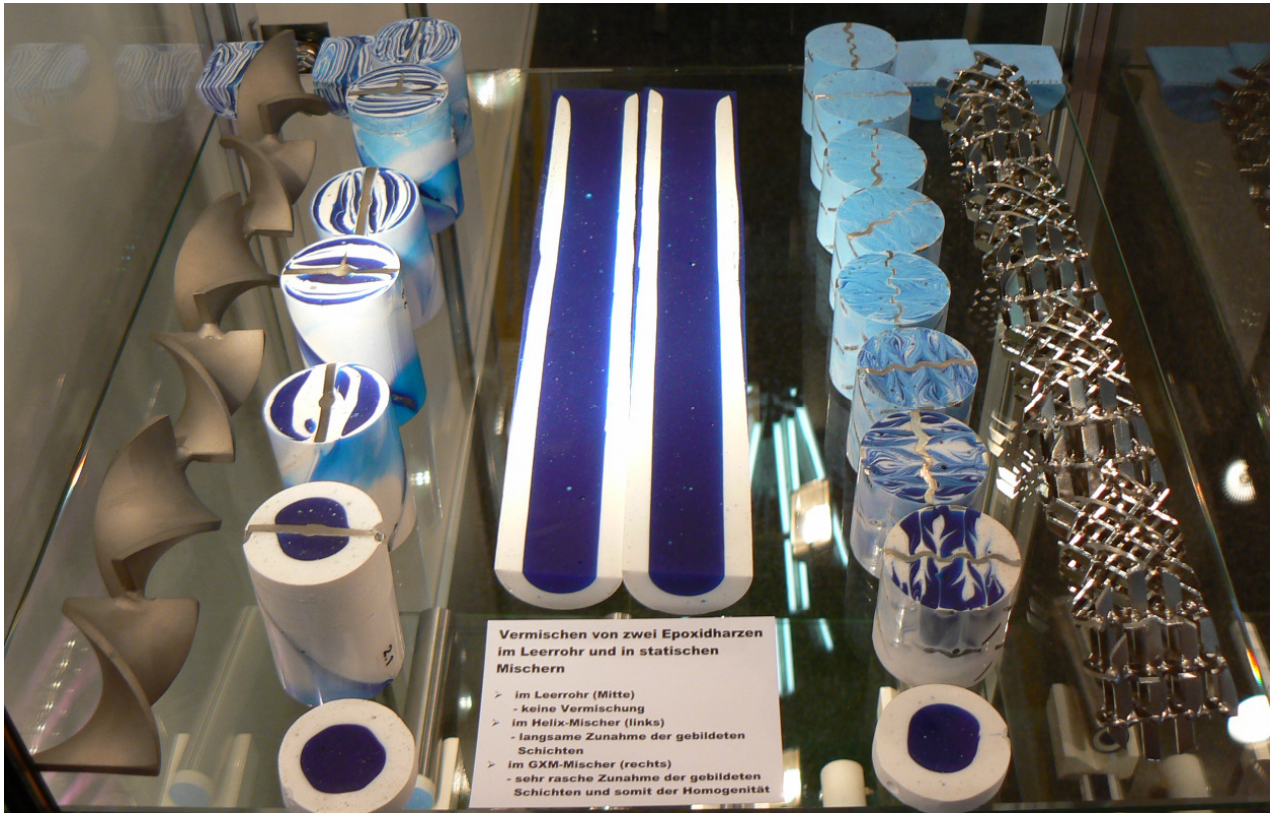


Extrusion Melt Blender

Purpose Function of a Static Mixer

- Homogenize the melt just upstream of the mold/die
- Homogenization is the creation of a uniform material which is alike throughout all its parts.
- Critical properties requiring homogenization in extrusion and injection molding are:
  - ❖ Concentration Properties of the Melt
  - ❖Thermal Properties of the Melt

Static Mixers Used for Polymer Processing (1)



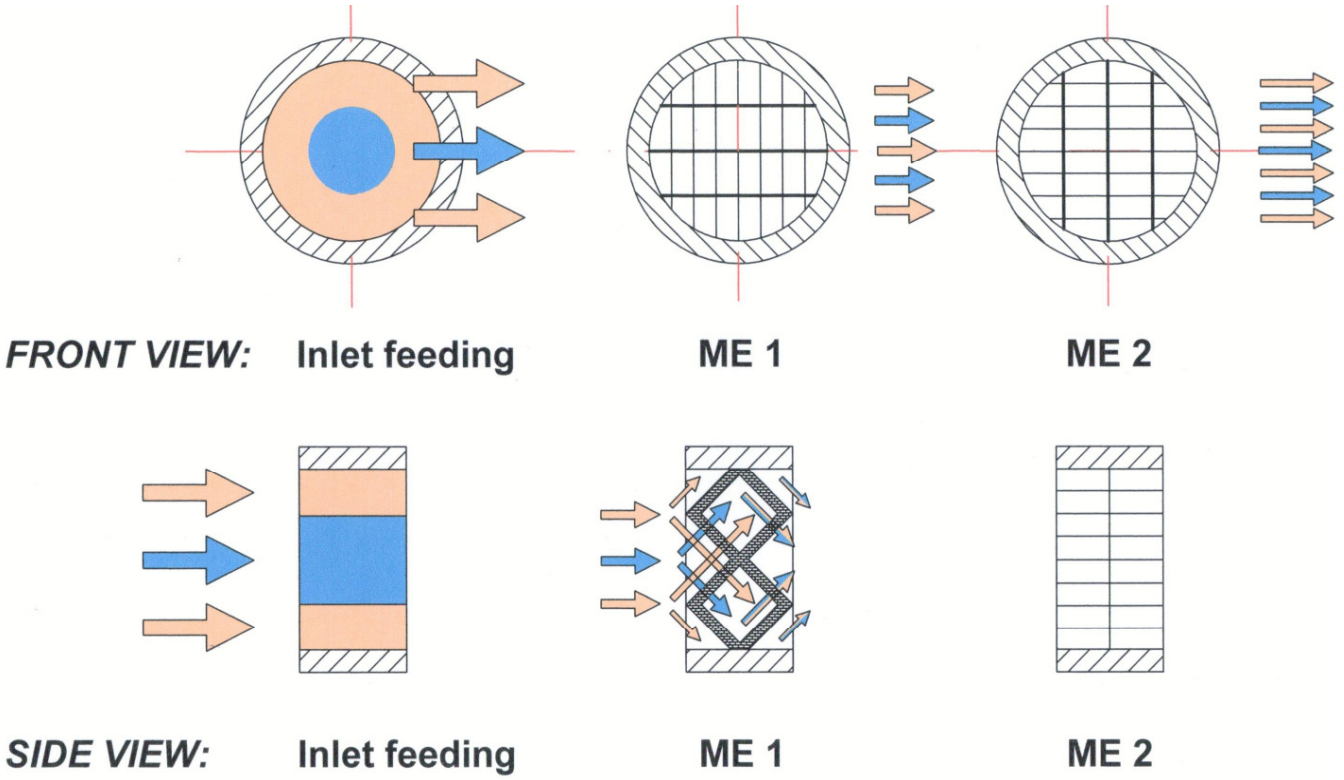
Helical Type **Empty Pipe** **X-Type**

Static Mixers Used for Polymer Processing (2)

Top row: **ISG Type** **„House“ Design** **Empty Pipe**

Bottom row: **X-Typ with ring** **3-Blade Helical** **Pineapple** **XPS**

How Does a Static Mixer Work?



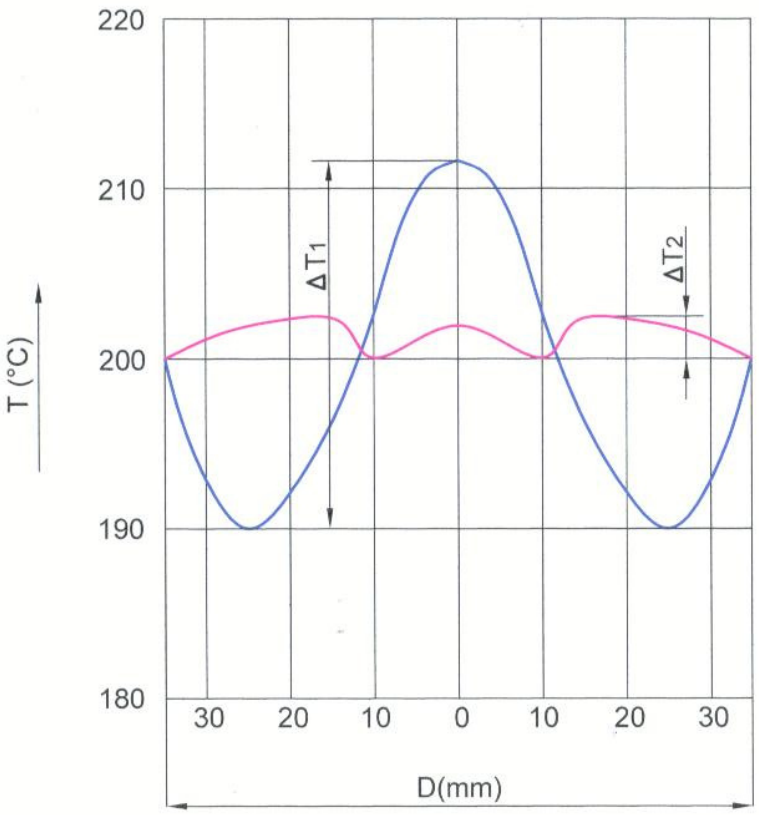
- Flow split into layers which are rearranged and forced to flow in radial direction
- Adjacent mixing elements are offset by 90°
  → assures uniform distribution over entire cross section

Mass Homogenization

WITHOUT STATIC MIXER
2% MASTER BATCH

WITH STATIC MIXER
2% MASTER BATCH

Temperature Homogenization

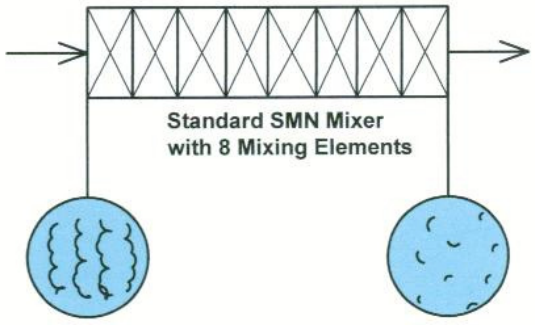


- Temperature profile after screw
  - without mixing device
  - downstream of static X-Type mixer (e.g. SMB, SMN)
- A non-uniform temperature leads to local differences in flow velocity

$$\Delta p = f\ (\dot{V} \times \eta)\ and\ \eta = f\ (T)$$

→ Critical for
- wall thickness, cooling
- flow in distribution systems for uniform filling of cavities

Quantitative Mixing Performance



Inhomogeneity: inlet outlet

Standard Deviation: $S_0 = 1.0$ $S \approx 0.16$

increasing degree of mixing

Mixing Efficiency: $S/S_0 \approx 0.16/1.0 \approx 0.16$

Factor of Reduction of Inhomogeneities: $f = S_0/S \approx 1.0/0.16 \approx 6$

i. e. inhomogeneities (colorant concentration, temperature differences) will be reduced by the mixer by a factor $f \approx 6$

Mixing Performance is calculated as follows:

$S/So = k^{n_{ME}}$

e.g.
for StaMixCo Mixers

$S/So = 0.63^{0.5 \times n_{ME}}$

How to Calculate Pressure Drop?

Pressure drop: $$\Delta p = \frac{4}{\pi} Ne \, \mathrm{Re}_D \frac{\dot{V}}{D^3} \eta \frac{n_{ME}}{2}$$

Viscosity: $$\eta = f(\dot{\gamma}, T, polymer(type, grade), p_{op})$$

Shear-rate: $$\dot{\gamma} = f(\dot{V}, D_{ME}, geometry)$$

Typical $NeRe_D$-values:

- Helical Type: $NeRe_D \approx 250 - 400$
- X-Type: $NeRe_D \approx 1200 – 2000$ (- 3500)
- ISG: $NeRe_D \approx 9600$

Power Consumption by Pressure Drop

- Power consumption compared with dynamic mixers is low. It is calculated as follows:

$$P = \Delta p \times \dot{V}$$

- For a pressure drop of 50 bar and a flow rate of 0.3 m^3/h polymer, the power consumption is:

$$P = \frac{50 \times 10^5 \times 0.3}{3600} = 417\ W\ or \approx 0.4\ kW$$

Adiabatic Temperature Increase Resulting from Mixer Pressure Drop

- The temperature of the melt increases by the energy dissipated as follows:

$$\Delta T_{adiabatic} = \frac{\Delta p}{\rho \times c_p}$$

- Example:

$$\rho = 800 - 1200\ kg/m^3 \quad -> average \approx 1000\, kg/m^3$$

$$c_p = 1500 - 2500\, J/kg°C \quad -> average \approx 2000\, J/kg°C$$

$$\Delta p = 20\ bar = 2\times 10^6\ N/m^2$$

$$\Delta T_{adiabatic} = \frac{2\times 10^6}{10^3 \times 2\times 10^3} = 1°C/20\ bar$$

How are Static Mixers sized?

Factors influencing the design are:

- Factor of improvement of homogeneity needed
  → relative mixer length (L/D) / number of mixing elements
- Maximum allowable pressure drop
  → flow rate, viscosity (polymer, MFI, T, shear rate of mixer)
  → diameter, length of mixer (m),

Most Frequently Used Mixers

- Injection moulding
  - X-Type mixers
    - SMN of StaMixCo Technology
    - SMK / SIB of Sulzer Chemtech
  - ISG Type offered by many suppliers
- Extrusion
  - X-Type mixers
    - SMN of StaMixCo Technology
    - SMK / SIB of Sulzer Chemtech
  - Helical mixers offered by several suppliers

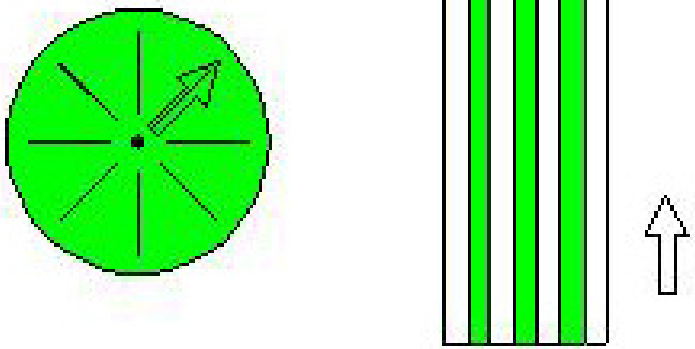
Typical Mixer Data

- Mixing efficiency
  - 90 % of the mixers are designed for a homogeneity improvement factor of 5 to 6
    → X Type mixers (StaMixCo, Sulzer): L/D = 4 - 5
    → Helical type (Kenics, others): L/D = 9 -12
- Diameter of mixer $D = f(n_{ME}, d.p.)$
  - Injection: approx. 0.2 to 0.3 x D_{screw}
  - Extrusion: approx. D = 0.5 to 1 x D_{screw}
- Typical pressure drop (for X-Type mixers)
  - Injection: approx. 100 – 200 bar
    → 10 – 20 bar of hydraulic oil pressure
  - Extrusion: approx. 30 – 60 bar

Mass Homogenization
When Does a Static Mixer Help?

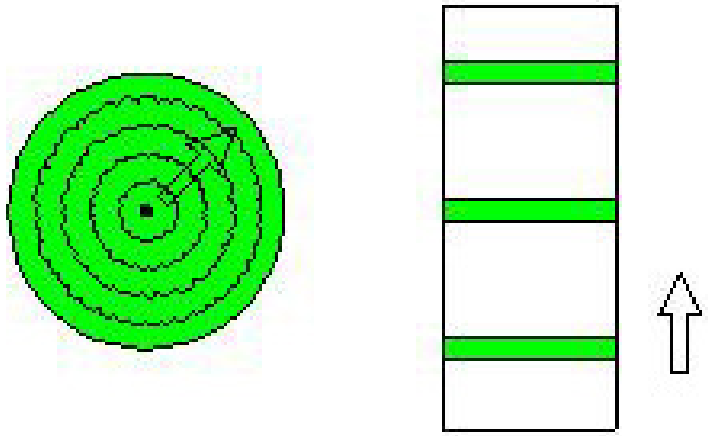
Streaks in Direction of Flow

- Static Mixer corrects streaks by mixing in radial direction



Streaks Perpendicular to Direction of Flow

- Static Mixers cannot correct streaks perpendicular to flow direction (needs axial mixing)
- Solution
  - Increase dosing rate
  - Increase back pressure



Limitations of Static Mixers

- A Static Mixer is a low shear equipment and thus suitable

  → for distributive mixing tasks

  → but not for dispersive mixing duties, e.g. to reduces size of agglomerated solids/ particles

- With Static Mixers most of the polymers can be processed like e.g.
  - Polyolefines (HDPE, LDPE, LLDPE, PP)
  - Styrenics (GPS, HIPS, ABS, SAN, etc.)
  - PET, PA (→ fibres)
  - others

  → but not for soft or rigid PVC (burns!)

Mass Homogenization

- Reduce spots, streaks, clouds of color
- Reduce colorant usage
- Maximize use of regrind
- Distribute additives

Colorant Saving
Pay-Back Time

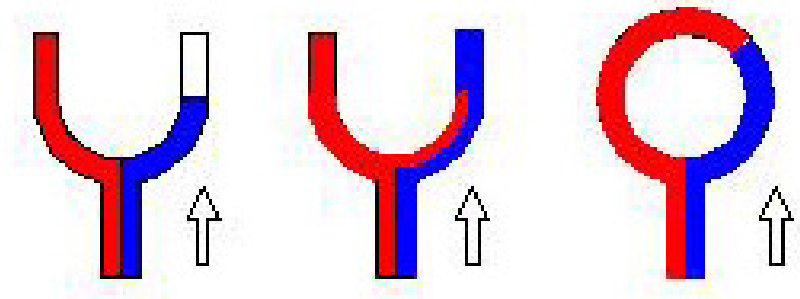
Polymer		**PS**
Polymer price	**USD/kg**	**2.0**
Colorant price	**USD/kg**	**30.00**
SMN Nozzle cost	**USD/kg**	**2000.00**
Part weight	**g**	**300.00**
Colorant portion	**%**	**0.50**
	g/part	**1.50**
Part cost	**USD/part**	**0.6420**
Cycle time	**sec**	**10.00**
Running time of machine	**h/day**	**16.00**
	days/week	**5.00**

Colorant reduction with SMN	**%**	**25.0**
Colorant saving	**g/part**	**0.38**
New part cost	**USD/part**	**0.6315**
Saving/part	**USD/part**	**0.0105**
SMN Mixing Nozzle amortized after:		
- number of cycles needed	**cycles**	**190476**
- number of hours need	**hours**	**529**
- number of days needed	**days**	**33.1**
- number of weeks needed	**weeks**	**6.6**

Temperature Homogenization Injection Molding

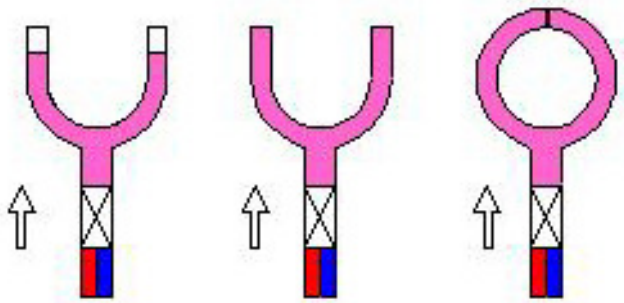
Poor Temperature Control

- Polymer melt with large DT
- Asymmetric filling
- Uneven cooling/Part distortion
- Part weight differences
- High reject rates



With Static Mixer

- Polymer melt with low DT
- Symmetrical filling
- Even cooling/No part distortion
- Constant weight
- Greatly reduced reject rates

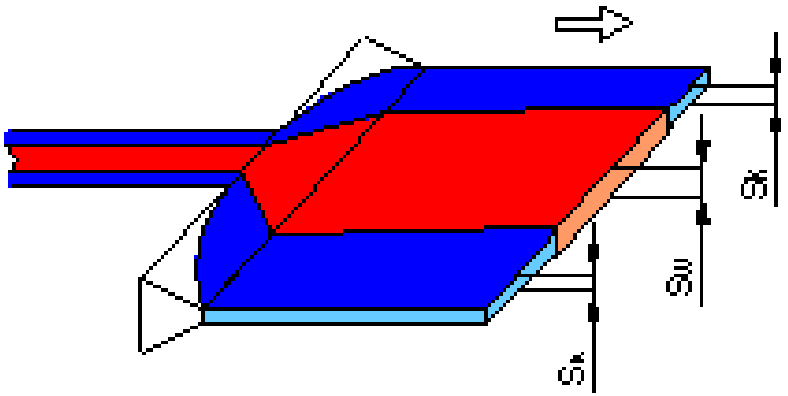


Temperature Homogenization Extrusion

Large Polymer Melt **DT**

Uneven plate, sheet & film thickness

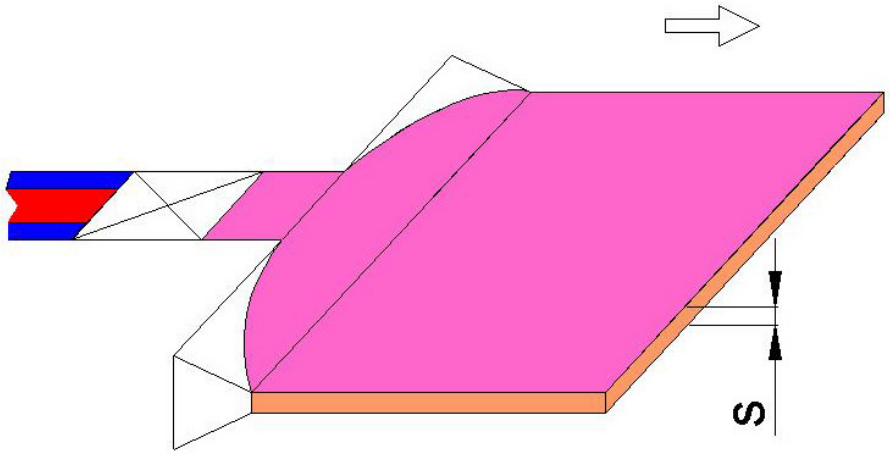
- Time consuming adjustment of die
- High reject rates during startup



With Static Mixer

Uniform plate, sheet & film thickness

- Die adjustments accomplished in a short time.
- Small reject rate during start-up.



Benefits of Mass and Thermal Homogenization in Injection Molding & Extrusion

Mass Homogenization

- Reduced spots, streaks and clouds of color
- Reduced colorant usage (10-40%)
- Even distribution of additives

Thermal Homogenization

- Narrower part tolerances
- Reduced reject rates
- Less part distortion
- Less part weight variation
- Improved product quality when using regrind. Ability to increase % regrind.
- Shorter cycle times
- Wall thickness and gauge control uniformity
- Foam cell size and distribution uniformity

End User Reasons for Installing Static Mixers

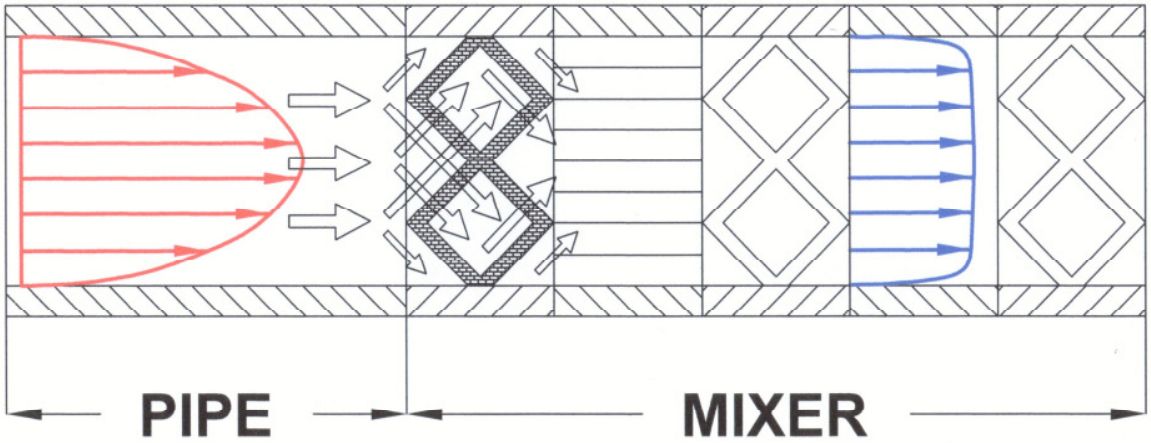
Injection Molding

- 70% of Static Mixer purchases by injection molders is for color homogenization (mass).
- Payback in normally less that 2 months based on more efficient use of colorant.

Extrusion

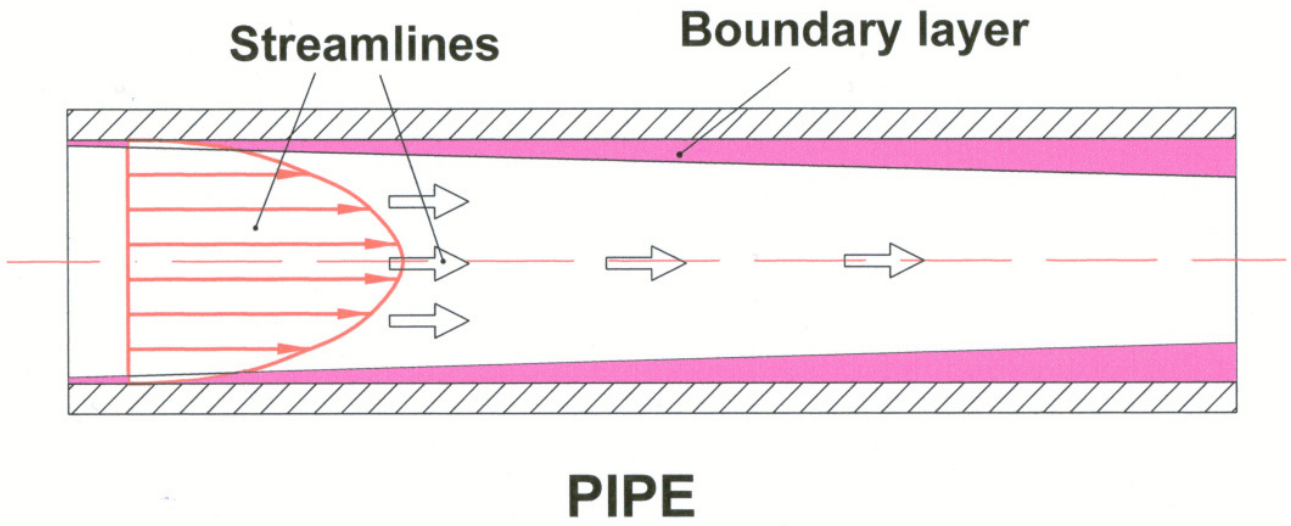
- 70% of Static Mixer purchases by extruder operators is for thermal homogenization
- Applications are for sheet & film gauge control, foam cell size uniformity & distribution, pipe wall, wire & cable and other thickness related issues.

Empty Pipe and Static Mixer Flow Profiles



- Empty Pipe Laminar flow profile
  → large velocity difference accross pipe diamater
  → broad residence time distribution
- Static Mixer Plug flow profile
  → very uniform velocity accross pipe diameter
  → narrow residence distribution

Self-Cleaning Empty Pipe

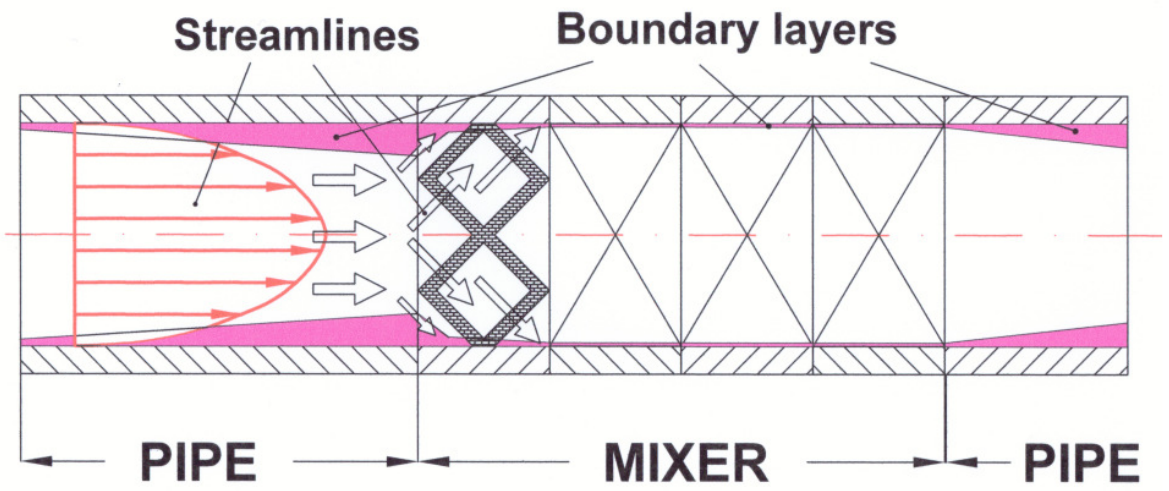


- Laminar flow profile: Flow of streamlines parallel to pipe wall
- At interface between streamlines and boundary layer some drag effect which removes boundary layer material

→ Reduction process is slow

→ Complete removal of the old material
= cleaning: requires **a lot** of material and long time

Self-Cleaning Static Mixer



- Pipe section at inlet: Laminar flow profile
- Mixer section: Plug flow profile
  - flow lines forced to flow in radial direction
  - streamlines attack bars of mixer grid and pipe wall under an angle
    → boundary layers are removed quickly
    → complete removal of the old material
    = cleaning: requires **few** material only or a short time
- Pipe section at outlet: Laminar flow profile

Summary about Cleaning

Section	Empty Pipe	Static Mixer	Empty Pipe	Die
Flow profile	laminar flow in axial direction only	like a plug, quite uniform, flow in radial direction	laminar flow in axial direction only	laminar main flow in axial direction
Material volume needed for cleaning	high	small	high	small
Spots of old material	mixed with new material in static mixer, becomes quickly invisible	mixed with new material in static mixer, becomes quickly invisible	not mixed material stays on pipe wall surfaces and slowly breaks off, remains visible	not mixed material stays on pipe wall surfaces like in empty pipe, remains visible

Conclusions

High Efficiency Static Mixers

- are efficient tools to improve melt homogeneity in extrusion and injection molding
- improve product quality at low investment costs
- upgrade performance of older machines
- lower manufacturing costs, e.g. by colorant savings and reduced reject rates
- Have a good performance/cost ratio and usually a short pay-back period, often less than 2 months.