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## Waste Management, Circular Economy and Environmental Security








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# TESTING THE RECYCLABILITY OF POLYMERS IN LABORATORY CONDITIONS

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# Year 2022: Facts on plastics

- Plastics directly determine our reality – both technically and ethically.
- Our standard of living is inconceivable without plastics.
- Plastics allowed **the development of all technologies and activities** of human life.
- **Big effort is still made to the property development and production of plastics.**
- **Plastic waste is still not resolved so far (!).**
- Consequences – plastic waste contaminates nearly the whole planet.
- Only in the last decade has the problem of plastic disposal finally been media solved.

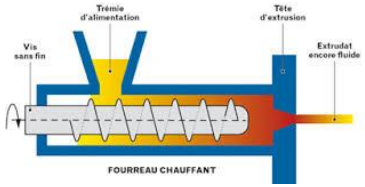
# How does plastic differ from classic materials?

- **Flexibility**
- **Easy processability**
- Price
- Mass
- Resistance to corrosion
- Mechanical properties such as strength, ductility, toughness
- Barrier properties
- Dyeability
- Organoleptic properties

*Plastics versus:*

**STONE WOOD METAL GLASS CERAMICS BIOPOLYMERS**

# Potential fate of plastics waste




| **Outdoor deposits** | **Landfill** | **Recycling** | **Waste-to-Energy** |
|---|---|---|---|
| Out of control | a) controlled<br>b) uncontrolled | a) direct<br>b) chemical | Professional |
| Worst | Wrong | Good/Best | Best at the presence |

# Laboratory approach X industrial approach

## LABORATORY

**Research facility**

**a) Commercial research facility**

**b) Academic research facility**

**Co-operation is needed**

## PRODUCTION

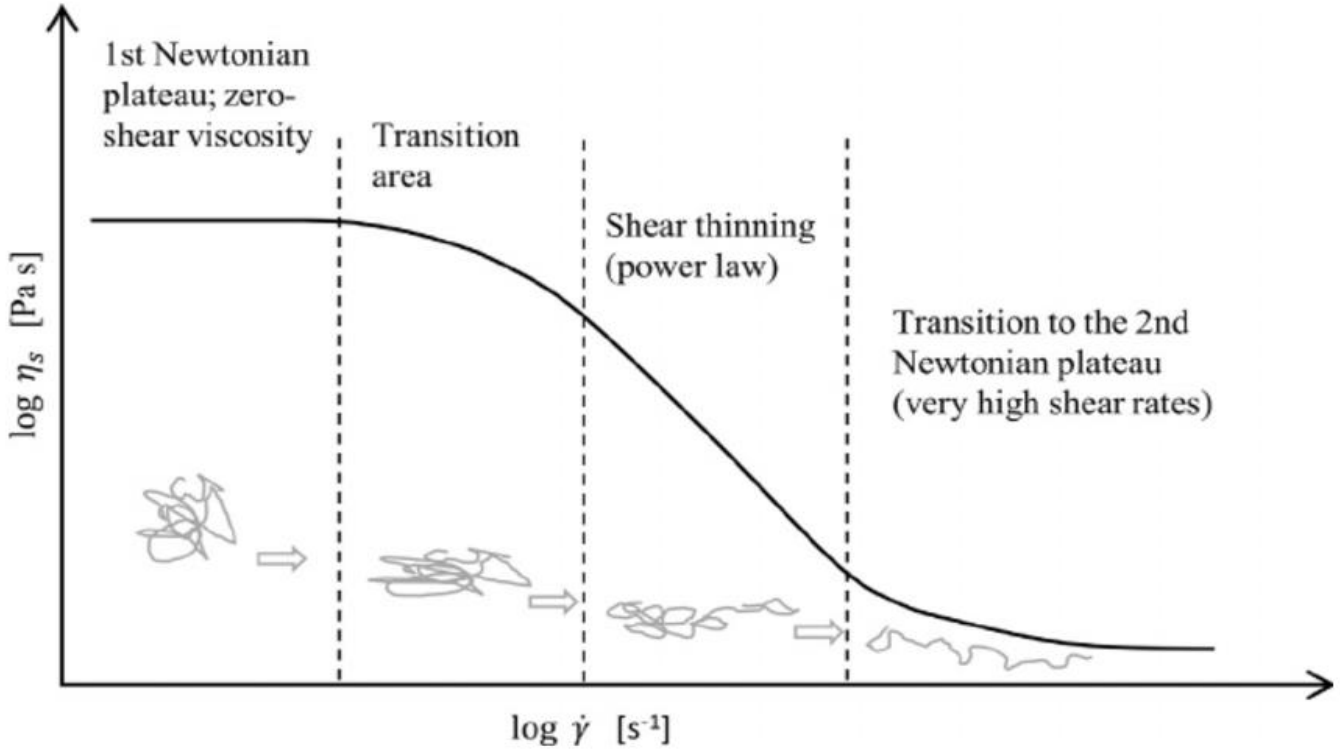
**Plant production facility**

**Standard plastics converter**

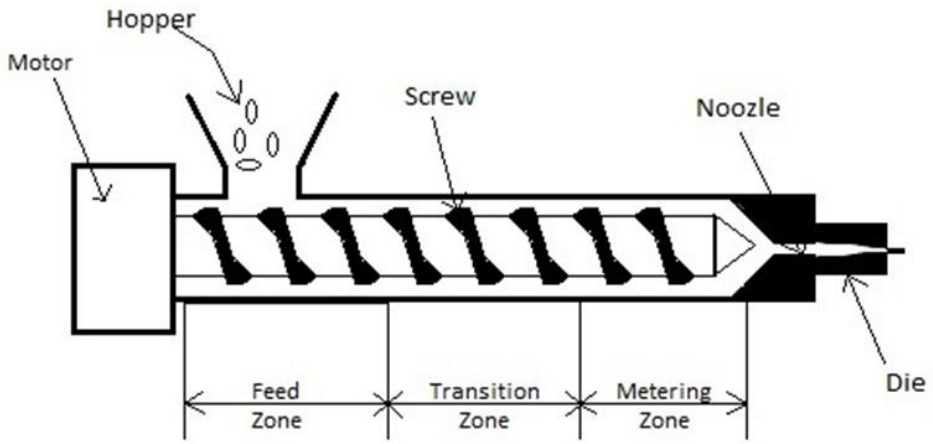
**Company specialized to plastics recyclate processing**

# Rheology of polymer melt

- Viscoelastic properties determine behaviour during processing.
- Energy needed for polymer melting, its homogenization and shaping into the final geometry determines the extent of mechanochemical deterioration of polymer.

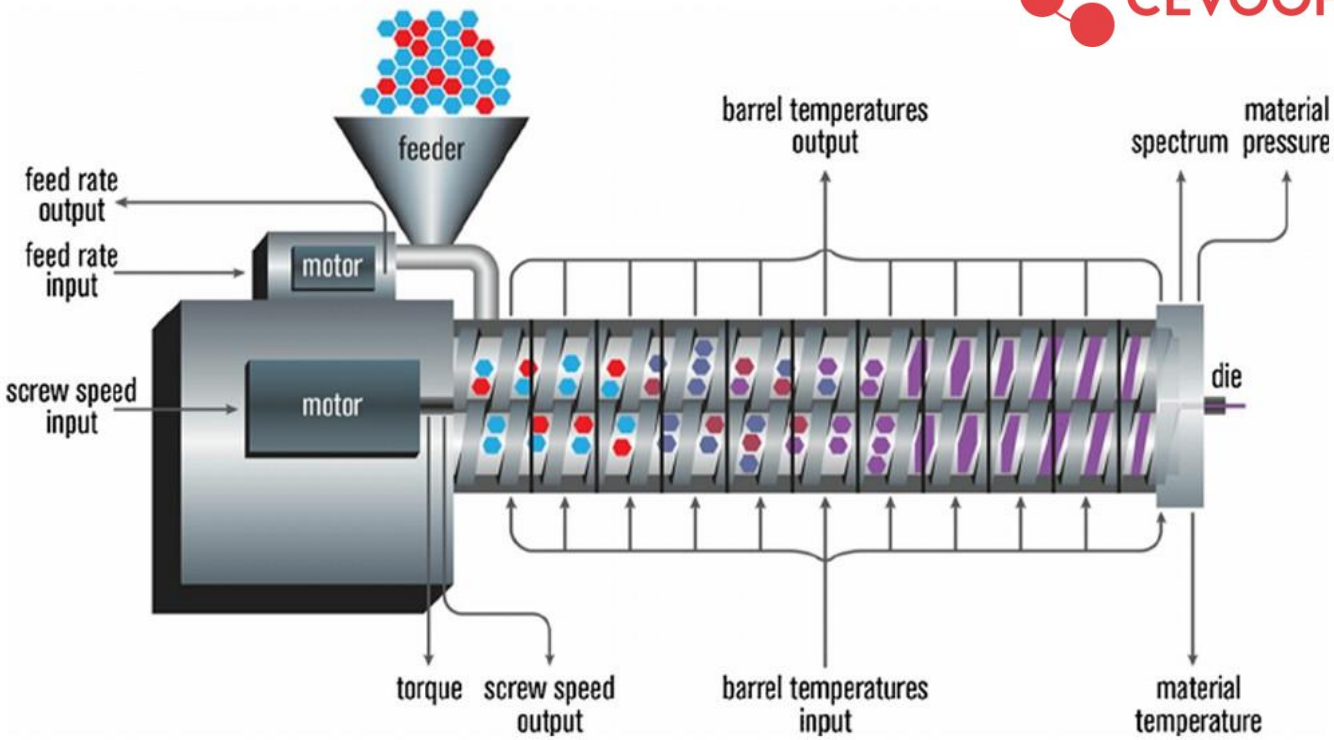


# Types of extruders



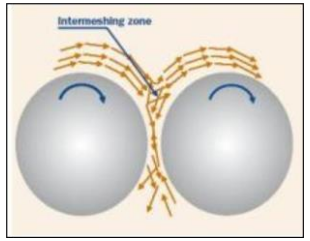

Extruder (single-screw)

Basic part of most of polymer-processing technologies




Extruder (twin-screw)

Polymer compounding with additives of substantially different properties




**Area of the highest mechanical stress**

# Specific features of plastics separated from municipal waste

- Variety of classes.
- Variety of types of the same polymer.
- Contamination.
- Degradative deterioration – **processing**, environmental.

# A case study – materials of drink bottle


*Cap (**HDPE**)*

*Bottle neck and thread (**PET** crystalline)*

*Bottle body (**PET** partly amorphous)*

*Label (**PP**-biaxially oriented)*

**HDPE (high-density polyethylene)**

**PET (polyethylene glycol terephthalate)**

**PP (polypropylene)**

to be tested in terms of recycling

# Materials investigated

1) PET-blue
2) PET-green
3) PET-transparent
4) HDPE-caps
5) HDPE-mix (ref.)
6) PP-labels

Processing stability
by **multiple extrusion.**

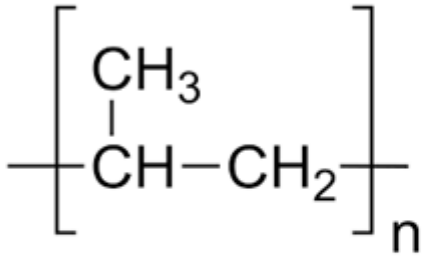
**Melt-index as a criterion of polymer deterioration.**

**Single-screw extruder HAAKE**
Screw diameter 19 mm
Length/diameter ratio = 25

**Origin:** Czech municipal waste.
**Polymers separated within the terrain research carried out as a part of project TIRSMZP719 complying with the newly certified methodology**.

## PP

Chemický název: Polypropylen; Poly(1-methylethan-1,2-diyl)

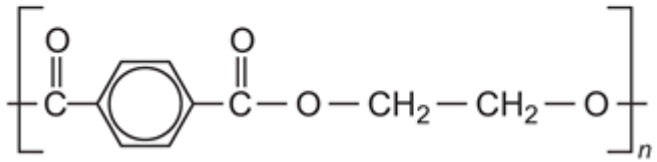


Typ plastu: semikrystalický polymer

Skelný přechod: -10 °C
Bod tání: 160-165 °C
Hustota: 0.905 g/cm$^3$ (homopolymer)
Teplota rozkladu: 447 °C

## PET/PETE

Chemický název: Polyethylen tereftalát; polyethylenglykol tereftalát

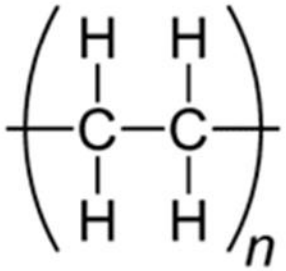


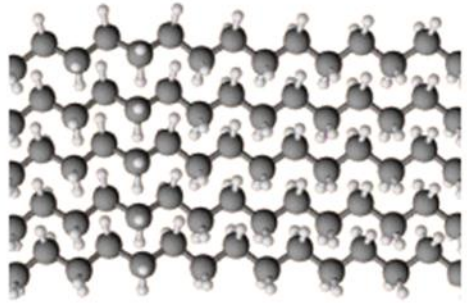
Typ plastu: semikrystalický polymer

Skelný přechod: 70-80 °C
Bod tání: 250-260 °C
Hustota: 1.38 – 1.40 g/cm$^3$
Teplota rozkladu: 425-440 °C

## HDPE

Chemický název: Vysokohustotní polyethylen; lineární polyethylen





Typ plastu: semikrystalický polymer

Skelný přechod: -100 °C
Bod tání: 125-138 °C
Hustota: HDPE ..... 0.940 - 0.960 g/cm$^3$ (high-density polyethylene)
UHMWPE ..... 0.930 - 0.940 g/cm$^3$ (ultra high-density polyethylene)
Teplota rozkladu: 485-495 °C

# Processing

Grinder

Material after grinding

Granulate – the end product of polymer waste processing

The way from the flaky waste to granulate is not so easy as it looks !

# Specific features of polymer waste laboratory processing

Playing a key role in success of laboratory testing

## 1. Physical form:

Has to comply with the cross section of hopper feeding area. Ground (or cut) polymer has to fall freely from the hopper down to the extruder screw.

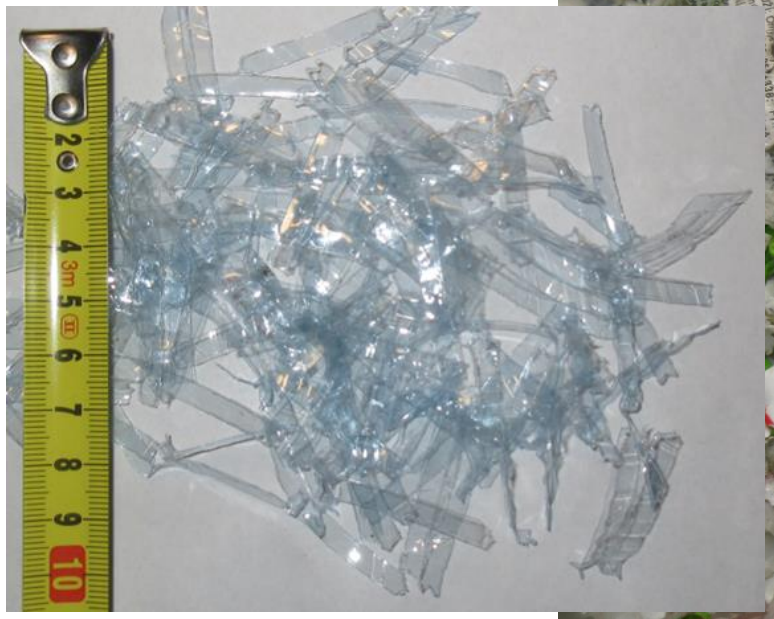
*In our case the hopper feeding area was the rounded rectanle 22 x 35 mm*

**Milling and grinding the polymer prior to extrusion is necessary!**

Effect of heat exposure on PET bottle-flakes size


Flakes-cut polymer | 200°C / 25 min. | 250°C / 10 min.

# Physical form unprocessable on laboratory equipment



PET

# Physical form – the final solution

Polymer ground and separated using 4 mm sieve
**Laboratory processable**

Particles above 4 mm sieve
**Laboratory non-acceptable**

# Specific features of polymer waste laboratory processing

Playing a key role in success of laboratory testing

## 2. Contaminants:

- Other polymers
- Dust
- Mechanical contaminants
- Volatiles
- Foodstuffs
- Chemicals
- Biological pollutions

**Manual separation and washing prior to extrusion is inevitable!**

*Paper bits (labels?)*


*Volatiles make the pellets spongy*

# Waste polymers for testing


HDPE-mix HDPE-caps PET-blue PET-green PET-transparent

**Density HDPE** (23 °C)

$\rho$ = 0.94-0.96 g/cm$^3$

**Density PET** (23 °C)

$\rho$ = 1.38-1.40 g/cm$^3$

# PET-blue

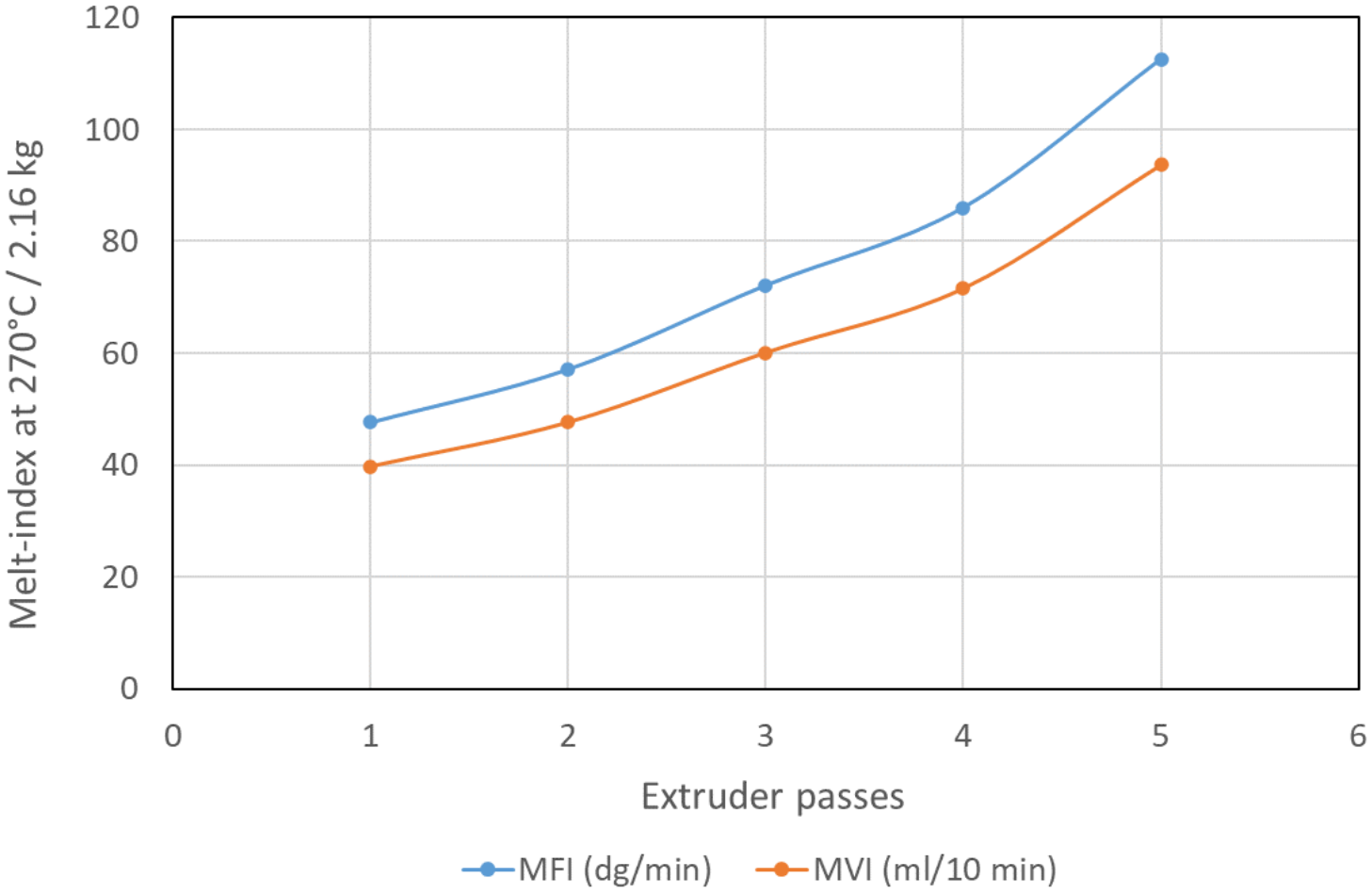
## Processing stability determination

HAAKE single-screw extruder
19 mm, L/D=25

5-fold extrusion at 275°C/80 rpm

Before and between extrusions
dried 3 hrs at 150 °C

Melt density 1.2 g/cm$^3$ used for
MFI calculation



# PET-green

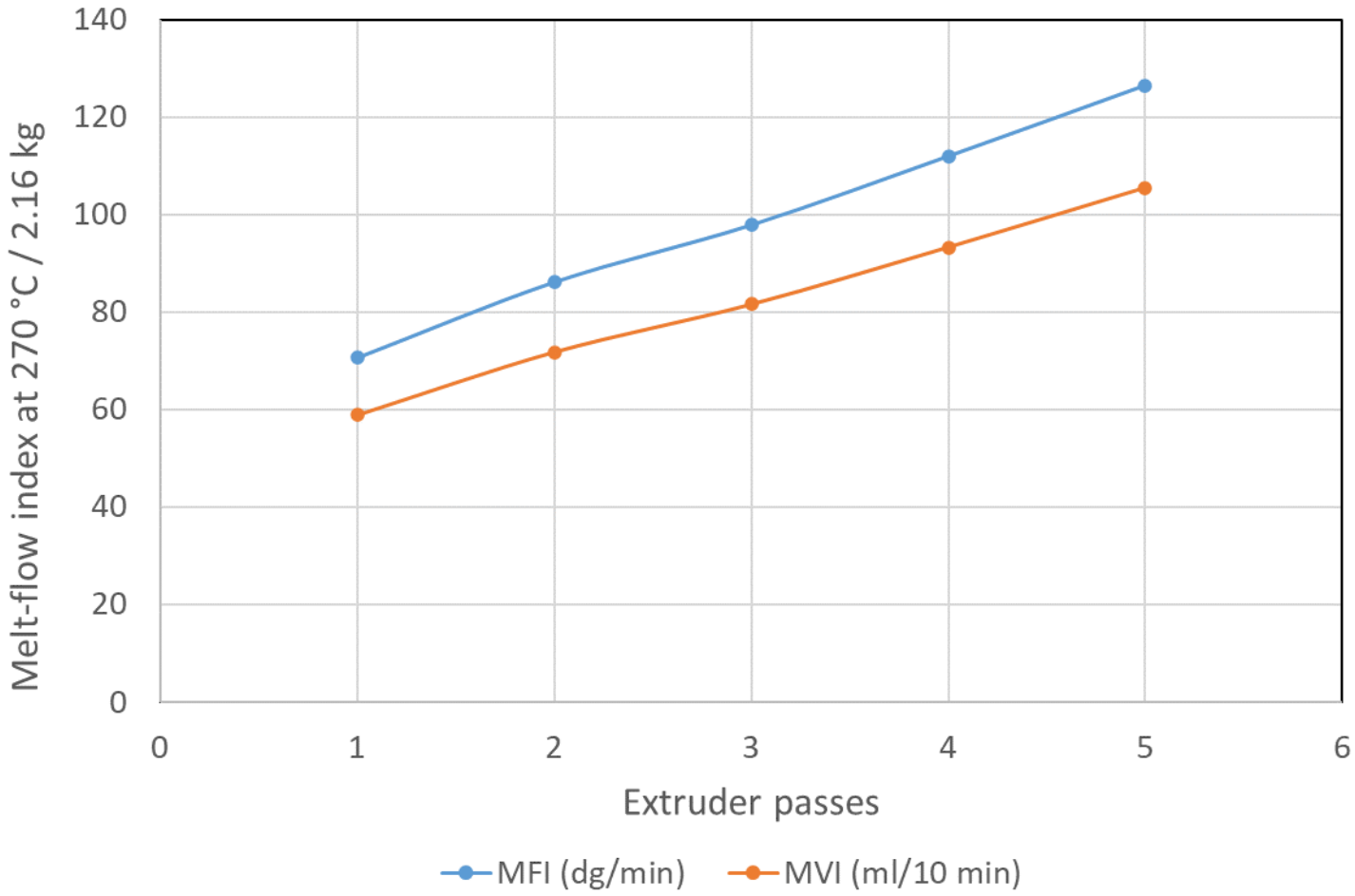
## Processing stability determination

HAAKE single-screw extruder
19 mm, L/D=25

5-fold extrusion at 275°C/80 rpm

Before and between extrusions
dried 3 hrs at 150 °C

Melt density 1.2 g/cm$^3$ used for
MFI calculation



# PET-transparent

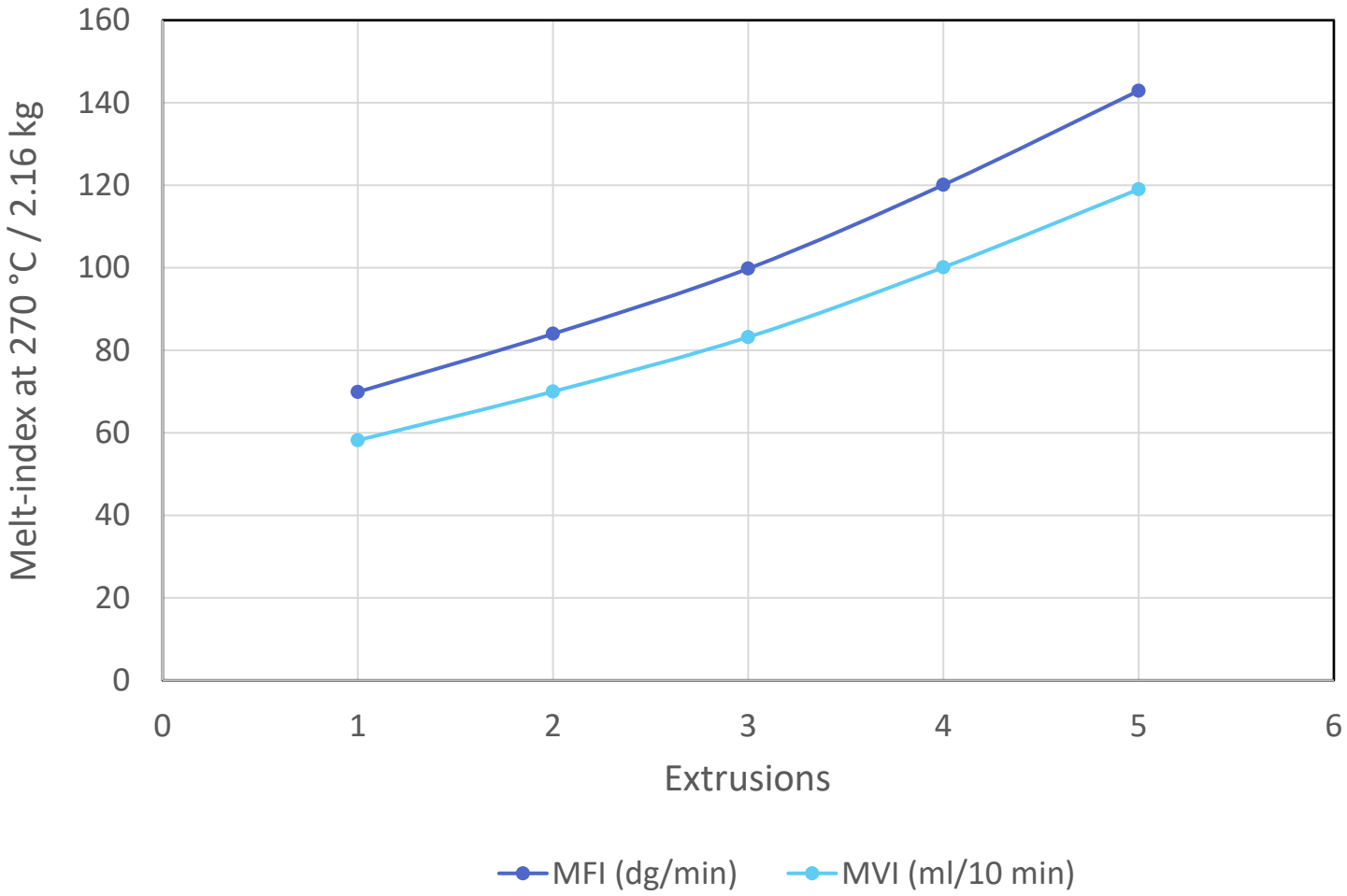
## Processing stability determination

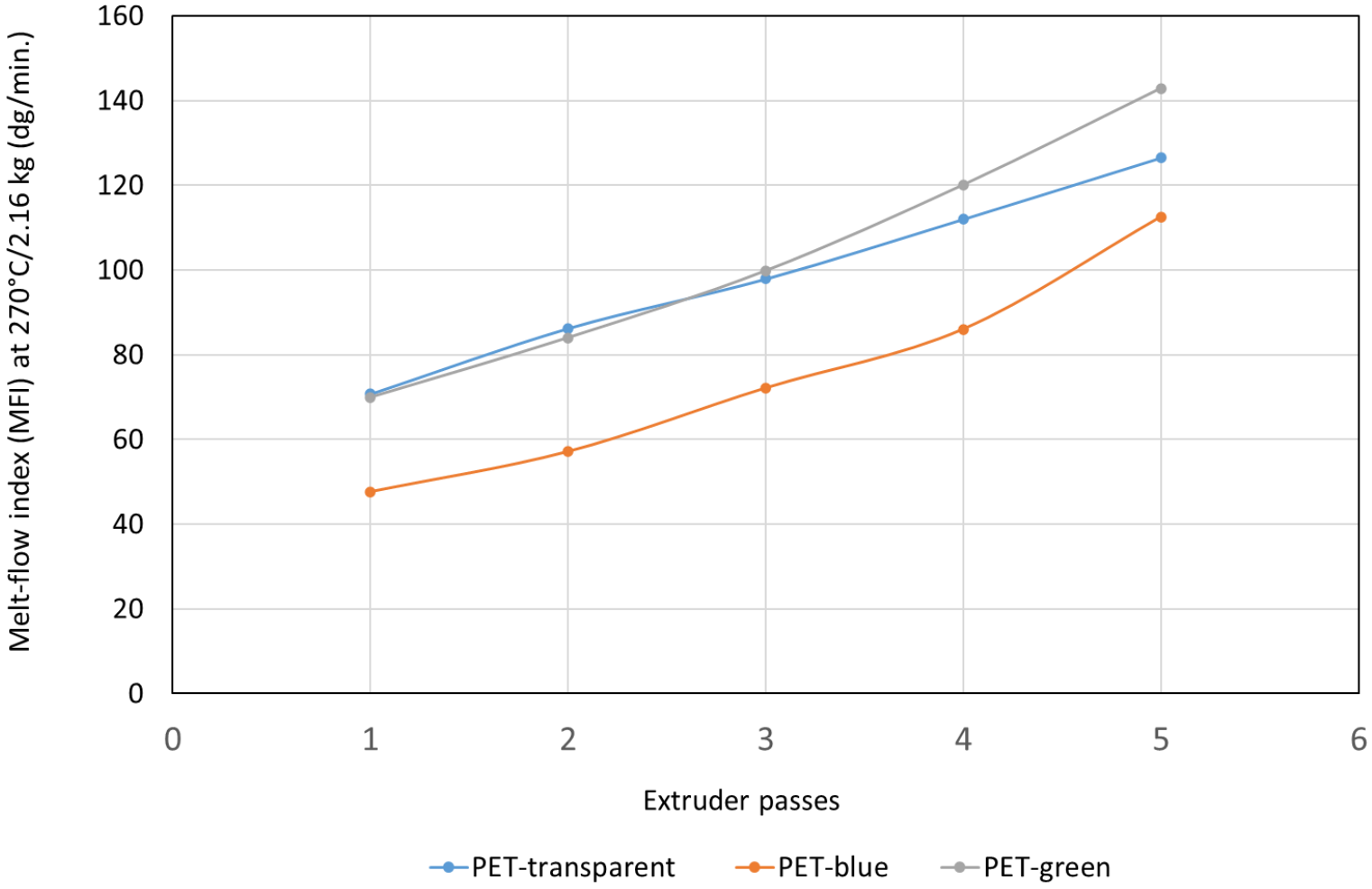
HAAKE single-screw extruder
19 mm, L/D=25

5-fold extrusion at 275°C/80 rpm

Before and between extrusions
dried 3 hrs at 150 °C

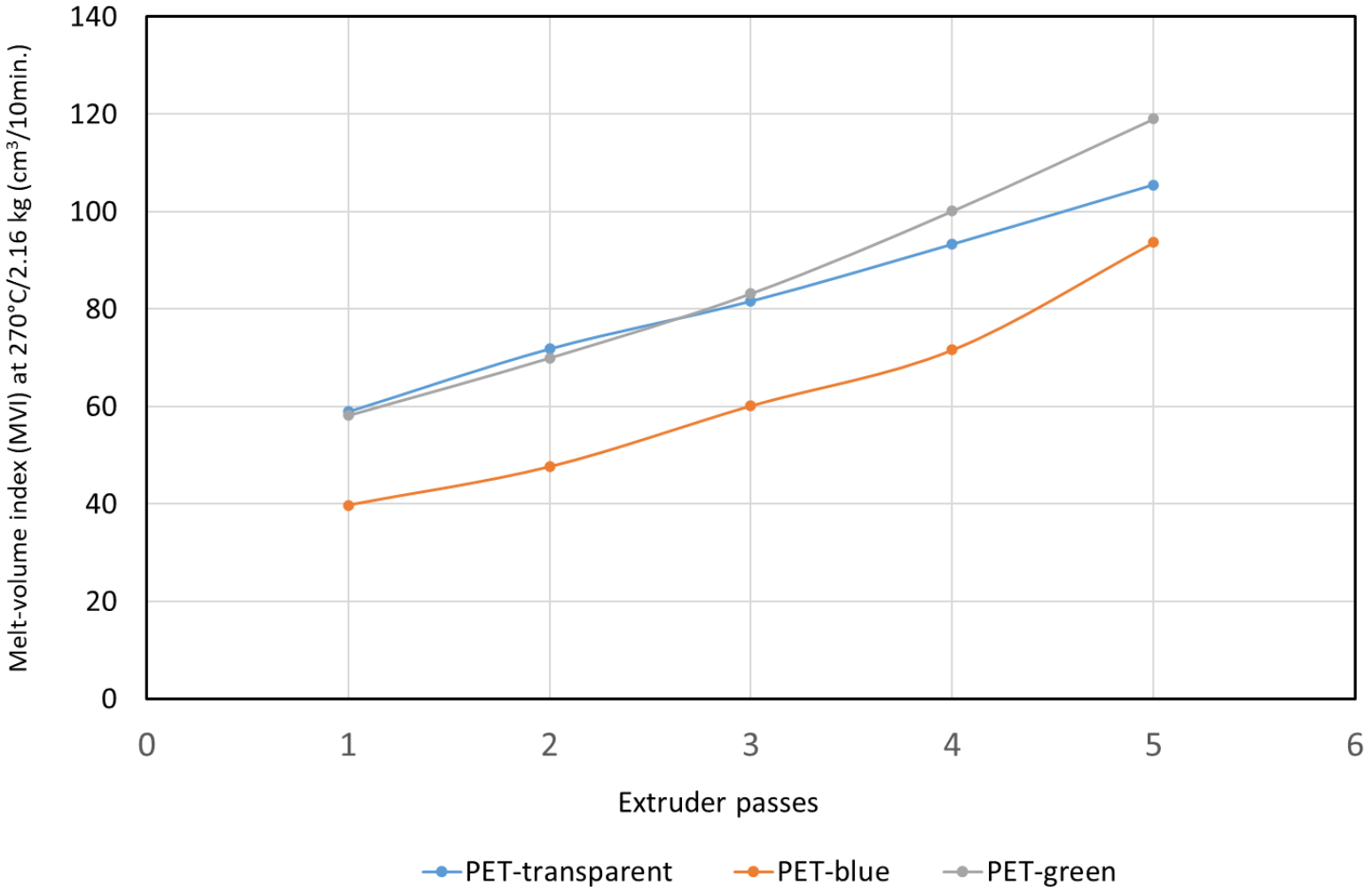
Melt density 1.2 g/cm$^3$ used for
MFI calculation






# Comparison PET

Processing stability overall comparison
(MFI - melt-flow index)




# Comparison PET

Processing stability overall comparison
(MVI - melt-volume index)

# HDPE-caps

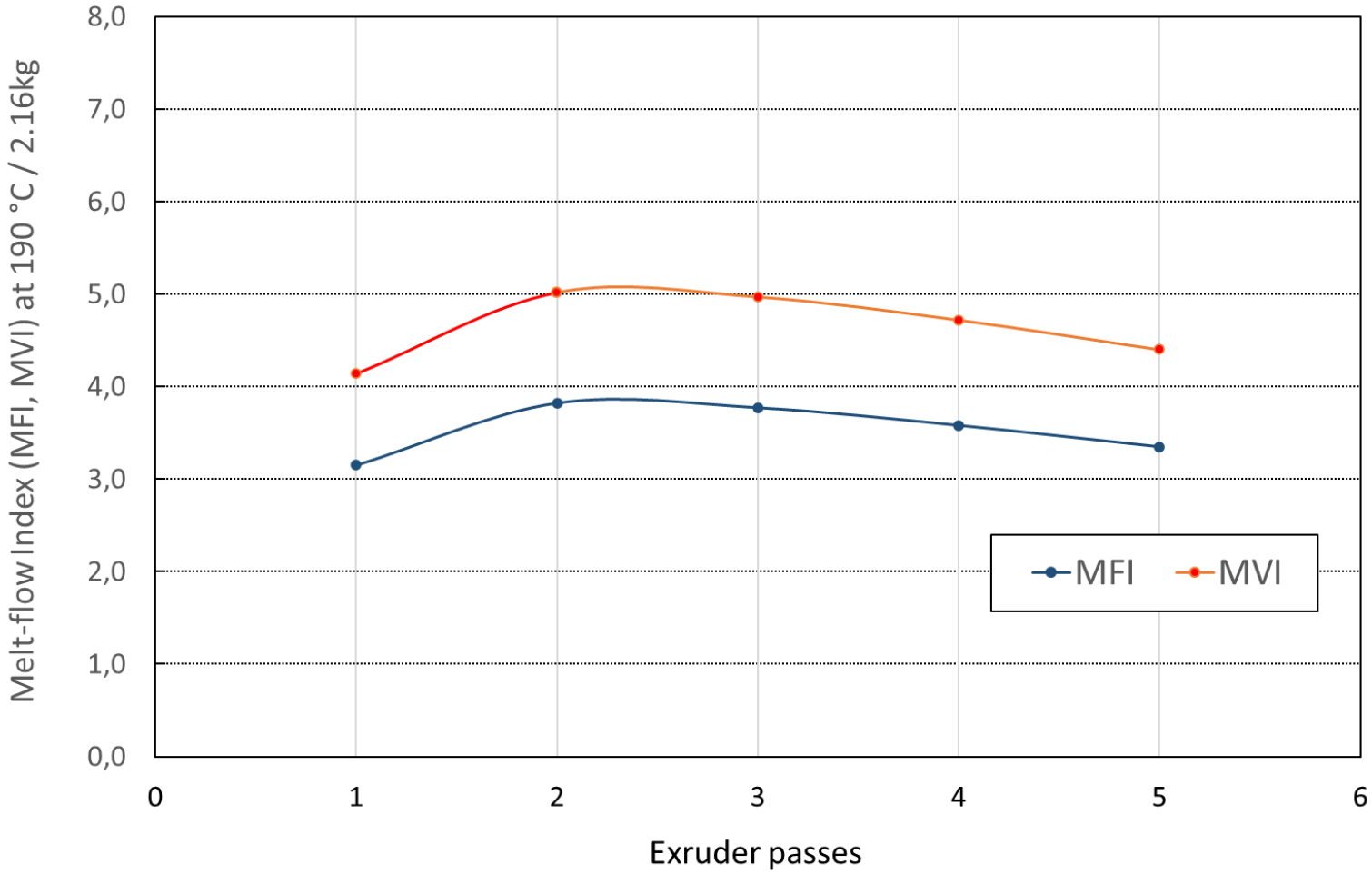
## Processing stability determination

HAAKE single-screw extruder
19 mm, L/D=25

5-fold extrusion at 240°C/100 rpm

No drying before and between extrusions

Melt density 0.76 g/cm$^3$ used for MFI calculation



# HDPE-mix

## Processing stability determination

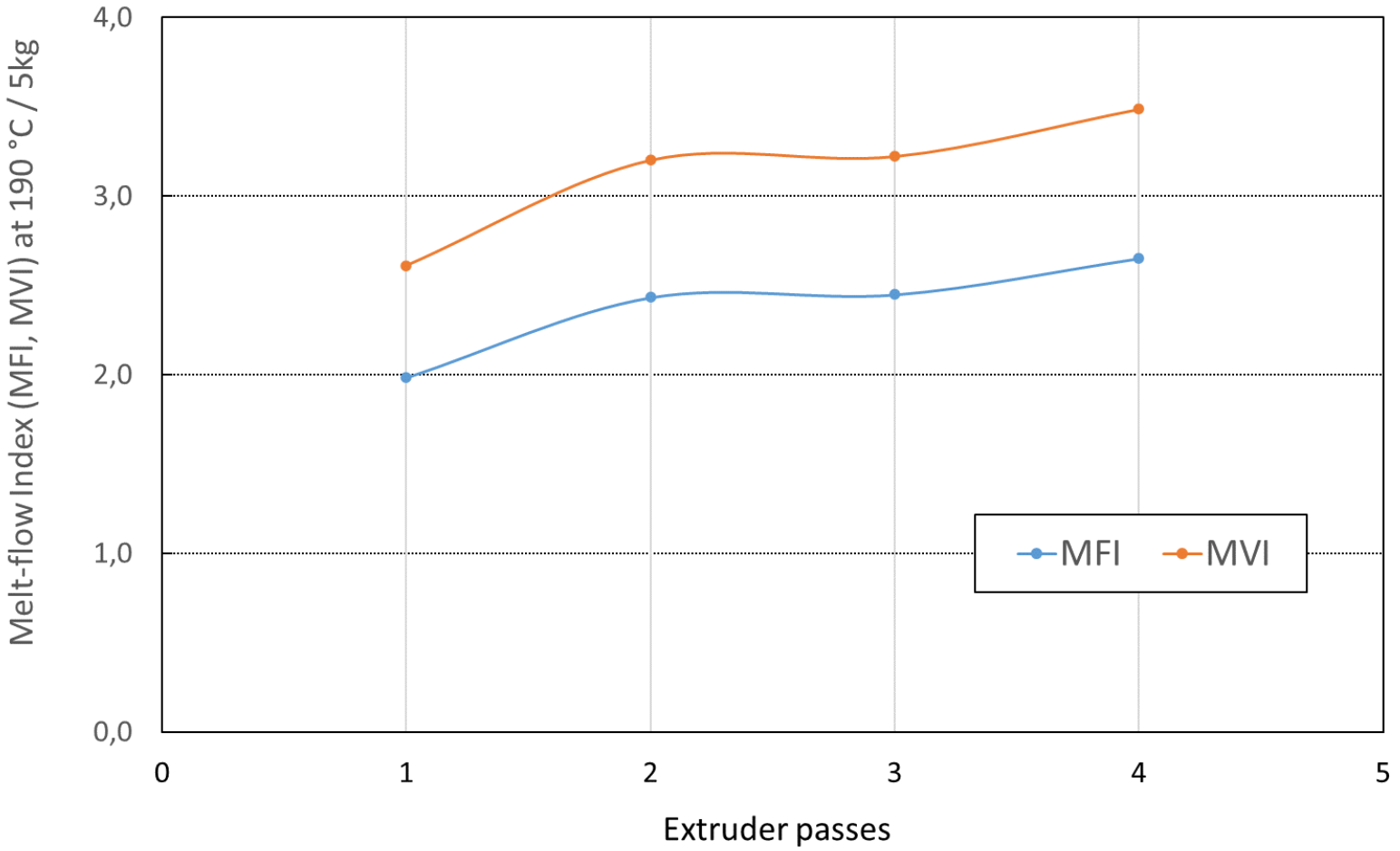
HAAKE single-screw extruder
19 mm, L/D=25

4-fold extrusion at 240°C/100 rpm

No drying before and between extrusions

Melt density 0.76 g/cm$^3$ used for MFI calculation

Reference material, not originating from drink bottles



# PP-labels

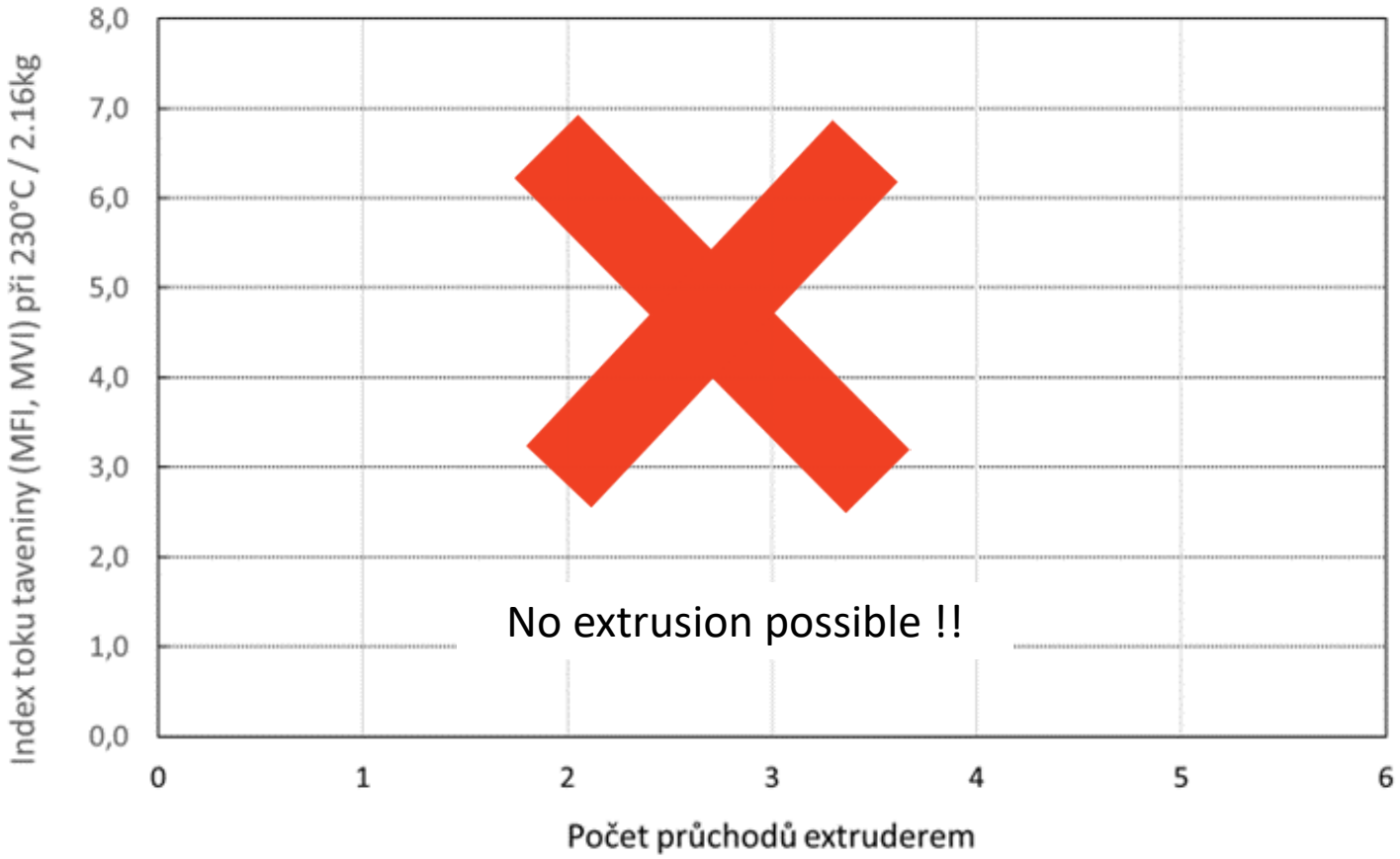
## Processing stability test

HAAKE single-screw extruder
19 mm, L/D=25

1-fold extrusion at 220°C/100 rpm

No drying before extrusion

**Observations:**
**Extremely low viscosity**
**Inhomogeneous melt**
**High portion of volatiles**
**Strong smell and smoke**




High surface/mass ratio and an extremely high portion of print colours on the film surface make the polymer label material unprocessable, i.e. useless (!)

# Conclusion (1)
# Role of laboratory testing

- **Laboratory tests are the first step** to the assessment of possible plastic waste re-processing.
- **Laboratory tests have technical draw-backs** that have to be taken into account when looking for the correlation with the plant processing line.
- Despite some specific features, **laboratory tests are irreplaceable both from the technical and economic reasons**. They will reveal if recycling the given material makes sense or not (!).

# Conclusion (2)
# Recycling and plastics life-time period

- Direct **recycling of any plastic** always provides material of **second-rate quality**.
- Direct **recycling does not solve the end of plastic life**. It only postpones it (!).
- Presently, **the real and most efficient elimination of plastic waste is reached only by Waste-to-Energy**.
- **Chemical recycling can be the potential future solution (!).**