Changeover time for single and twin-screw extruders

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Minimizing changeover time in extrusion

- Material and time is wasted during formulation changes
- Efficient changeovers improve environment and bottom line
- Goal: understand and compare changeover time for single and twin-screw extruders

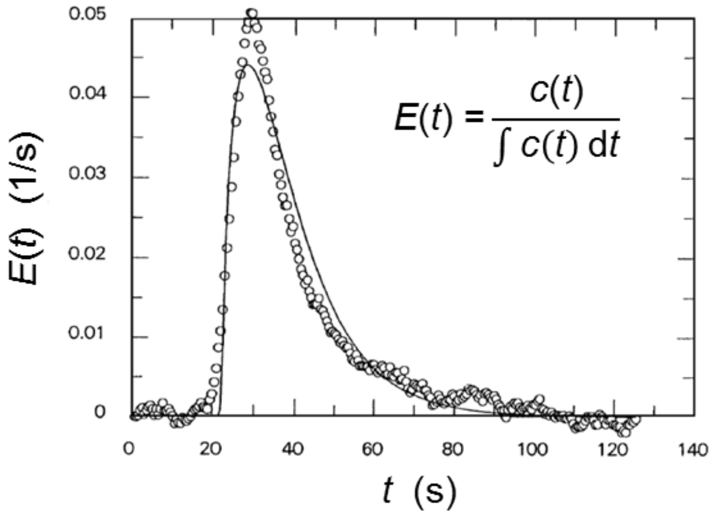
Operator: "Sometimes it takes days to purge out carbon black"

Image: Ultrapurge.com

Residence time vs changeover time

Residence Time

- Time for a fluid element to pass through extruder **at steady state**
- Reactive extrusion, mixing
- Pulsed tracer experiment
- Many reports and well studied



"Viscosity has little effect on twin screw extruder residence time"

Puaux et al, *Chem. Eng. Sci.*, 55: 1641 (**2000**);
Poulesquen et al. *Polym. Eng. Sci.*, 43(12): 1841 (**2003**)

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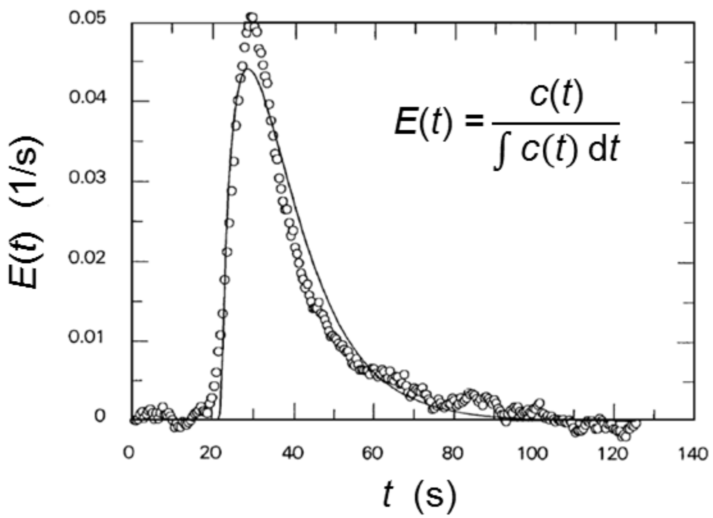

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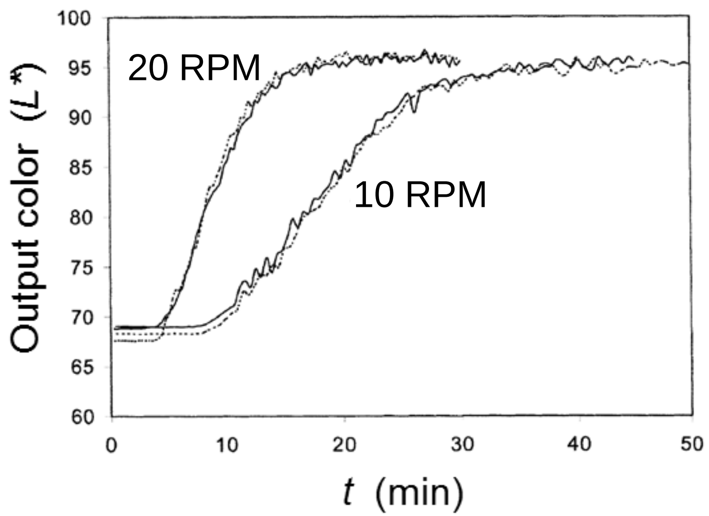
Changeover Time

- Time to change from one steady state to another, **transient**
- Product changeover, purging
- Industry experience but not many academic reports

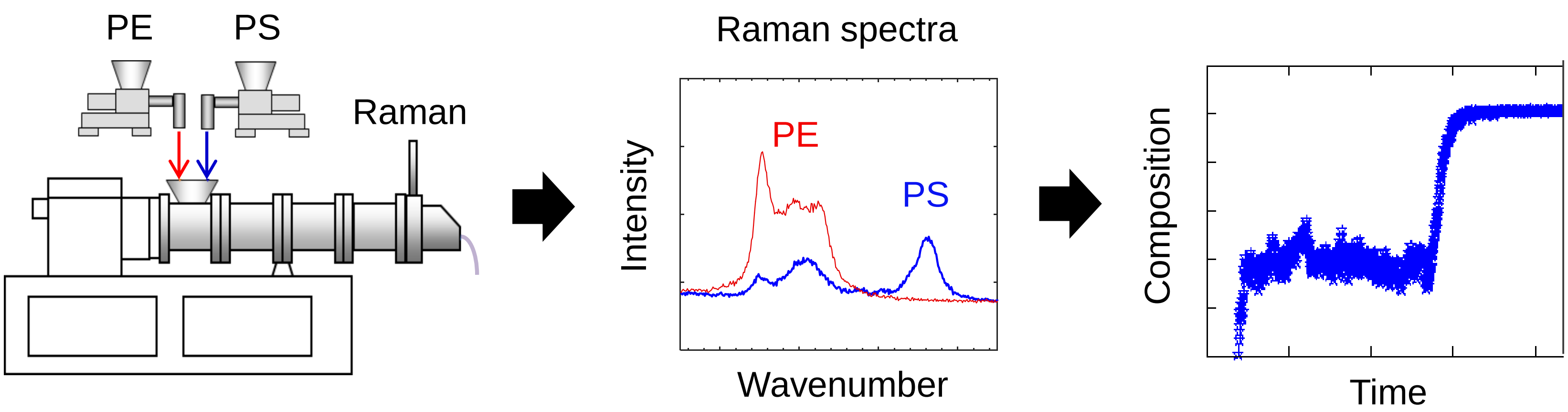


"Purging a high viscosity resin with low viscosity resin takes more time"

Gilmor et al., *Polym. Eng. Sci.*, 43(2): 356 (**2003**)

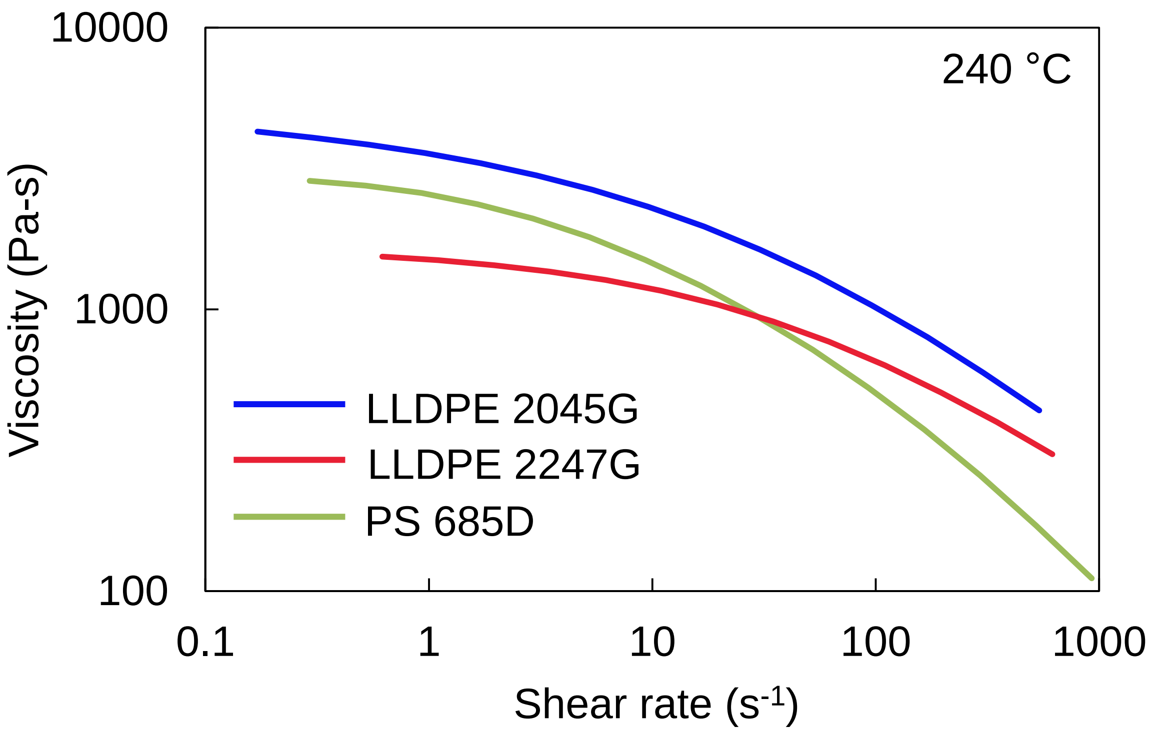
Online Raman spectroscopy for changeover time

- Switch polyethylene (PE) and polystyrene (PS) feed ratio
- Measure Raman spectra of extrudate over time
- Convert to composition – time plots, extract changeover time



Materials

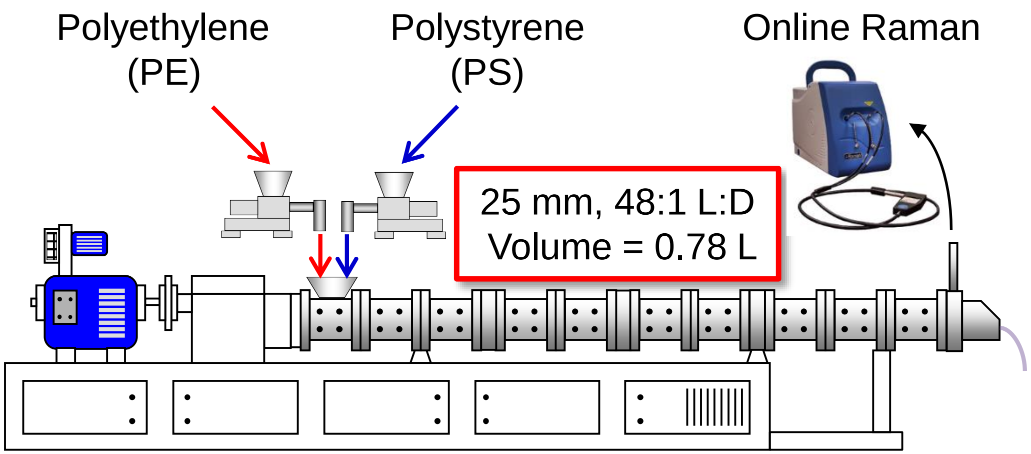
Name	Notation	MFI	Density (g/cm^3)
DOWLEX™ 2045G	LLDPE 2045G	1.0	0.920
DOWLEX™ 2247G	LLDPE 2247G	2.3	0.917
Styron 685D	PS 685D	1.5	1.05



™ registered trademark of The Dow Chemical Company

Experimental setup

Twin-screw extruder setup

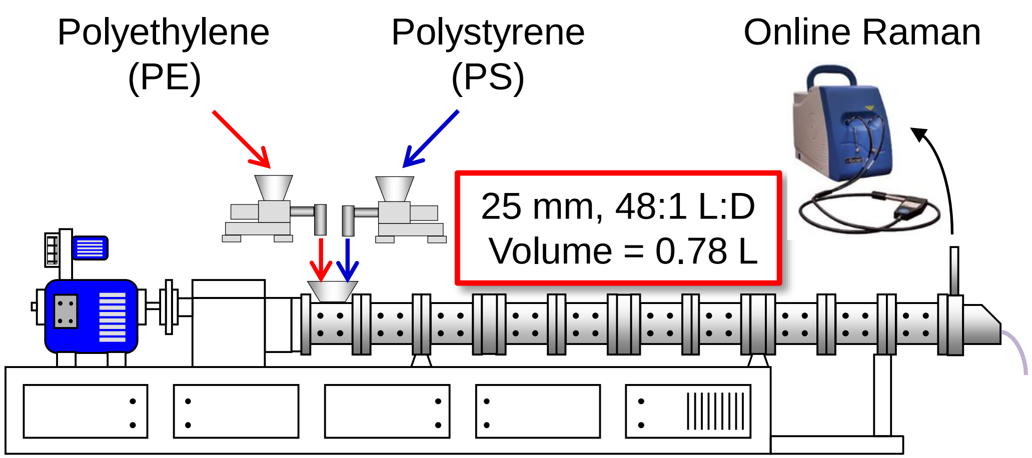


- Mass flow rate (10, 20 lb/h)
- Viscosity ratio (1.0, 6.4 MI PE)
- Screw speed (400, 500 rpm)
- Mixing zone location (barrel 3 or 7)
- Composition change
  100/0 → 50/50 → 0/100 →
  50/50 → 100/0 (PE/PS wt%)

Wang et al., *ANTEC Papers*, **2016**

Experimental setup

Twin-screw extruder setup



Wang et al., *ANTEC Papers*, **2016**

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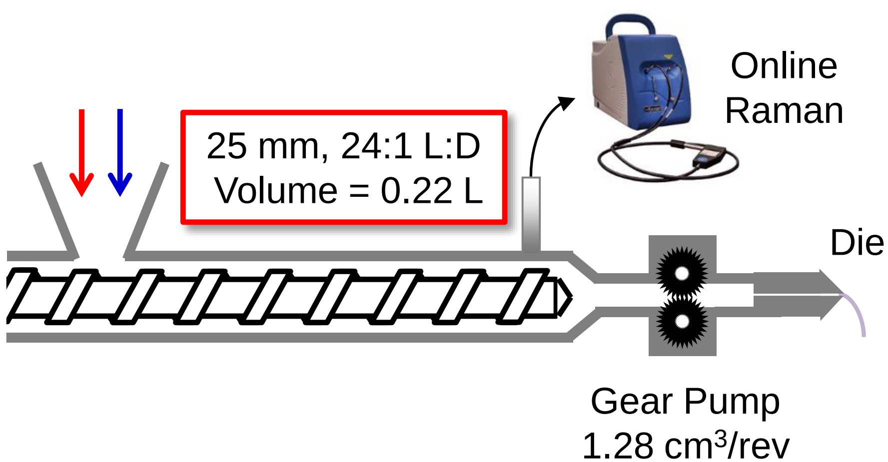
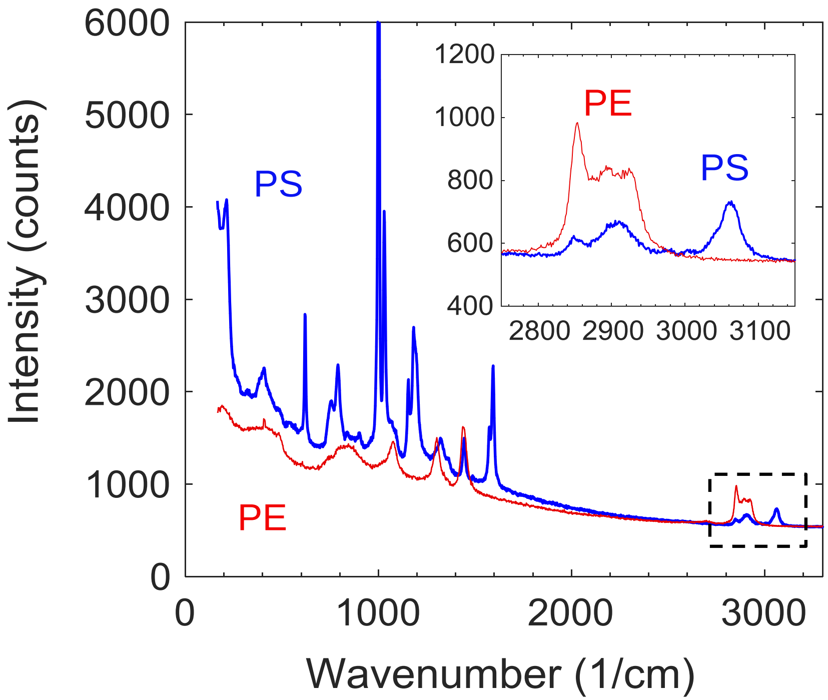
Single-screw extruder setup



- Mass flow rate (4, 10 lb/h)
- Viscosity ratio (1.0, 2.3 MI PE)
- Composition change
  100/0 → 50/50 → 0/100 →
  50/50 → 100/0 (PE/PS wt%)

Accurate compositions from Raman spectra

- Classical least squares method (CLS)
- Fit a linear combination of pure PE and PS spectra to sample spectra
- Linear combination pre-factors are related to concentrations



① Classical least squares (CLS)

Sample = C_1 × PS + C_2 × PE

② Intensity correction factor

$$I = \alpha V C W$$

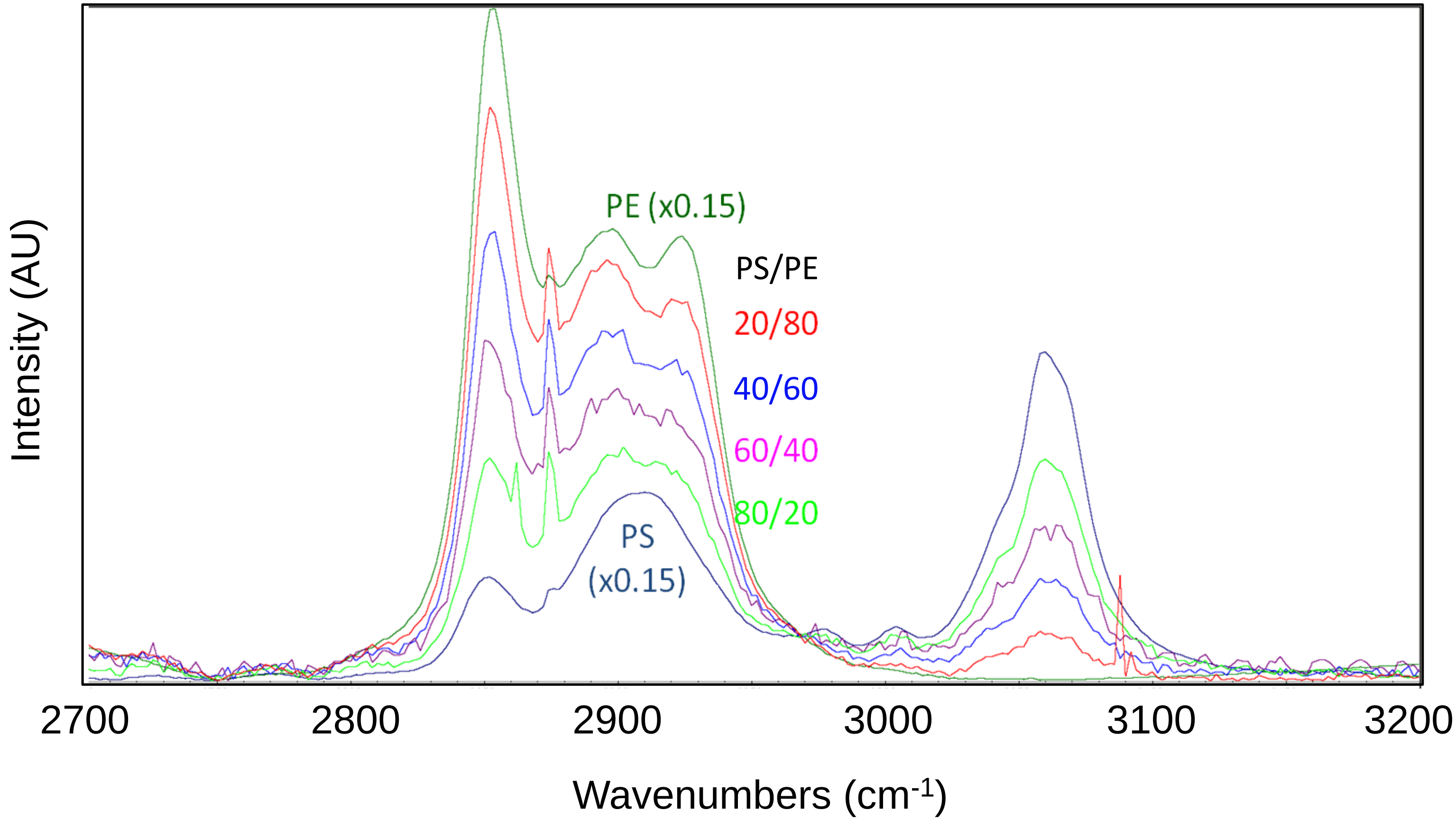
$$\frac{I_{\mathrm{PE}}}{I_{\mathrm{PS}}} = \frac{\alpha_{\mathrm{PE}}}{\alpha_{\mathrm{PS}}} \frac{C_{\mathrm{PE}}}{C_{\mathrm{PS}}}$$

I: Raman signal intensity
α: Raman cross-section
V: Effective focal volume
C: Concentration
W: Excitation laser power

Haaland et al., *App. Spectr.*, **1995**

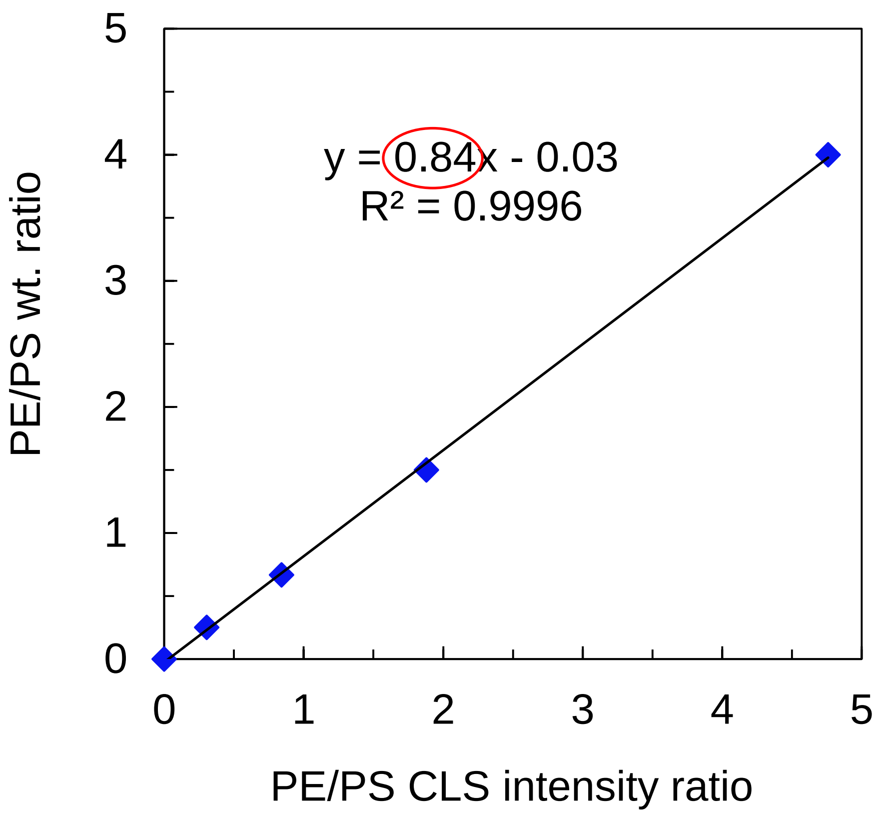
Raman calibration across range of compositions

- Correction term is necessary to account for melt transparency
- Online Raman spectra collected at a variety of steady-state compositions



Quantitation from Raman signal

- Very good linear relationship between CLS intensity and concentration
- More accurate than visual observation of colorants



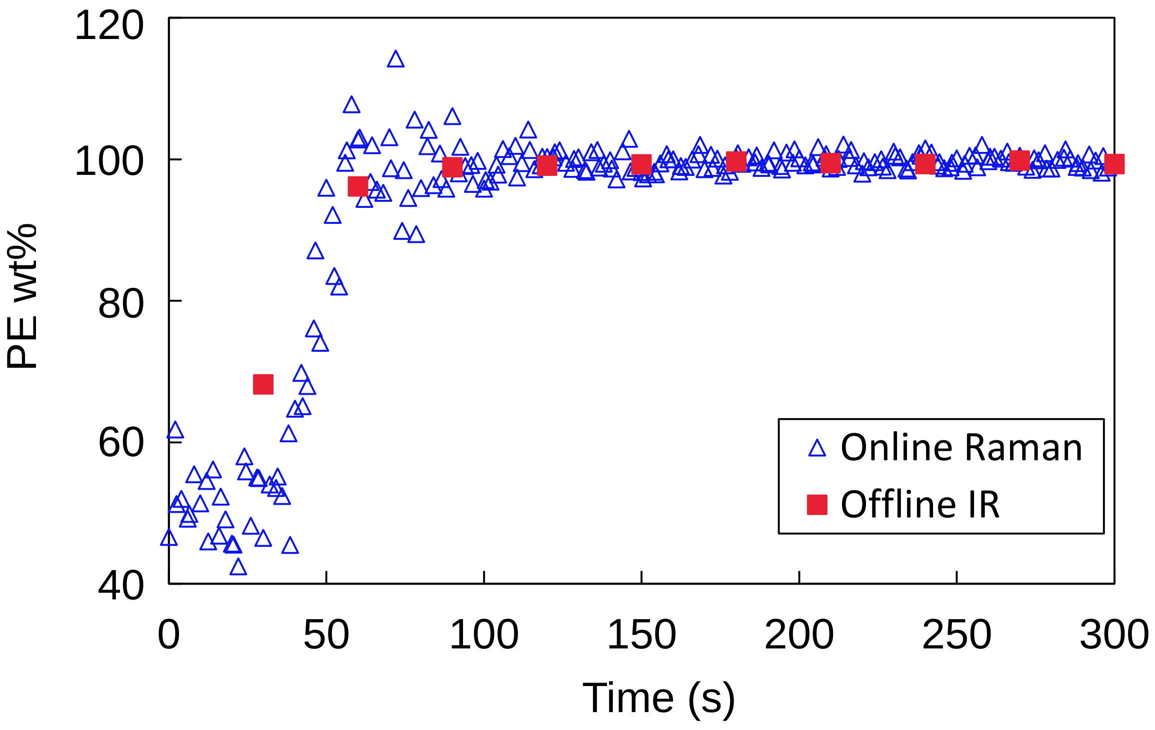
$$\frac{I_{PE}}{I_{PS}} = \frac{\alpha_{PE}}{\alpha_{PS}} \frac{C_{PE}}{C_{PS}}$$

α_{PE}/α_{PS}: calculated based on calibration samples

Haaland et al., *Applied Spectroscopy*, **1985**
Haaland et al., *Applied Spectroscopy*, **1980**
Beebe et al., "Chemometrics: A practical guide", Wiley.

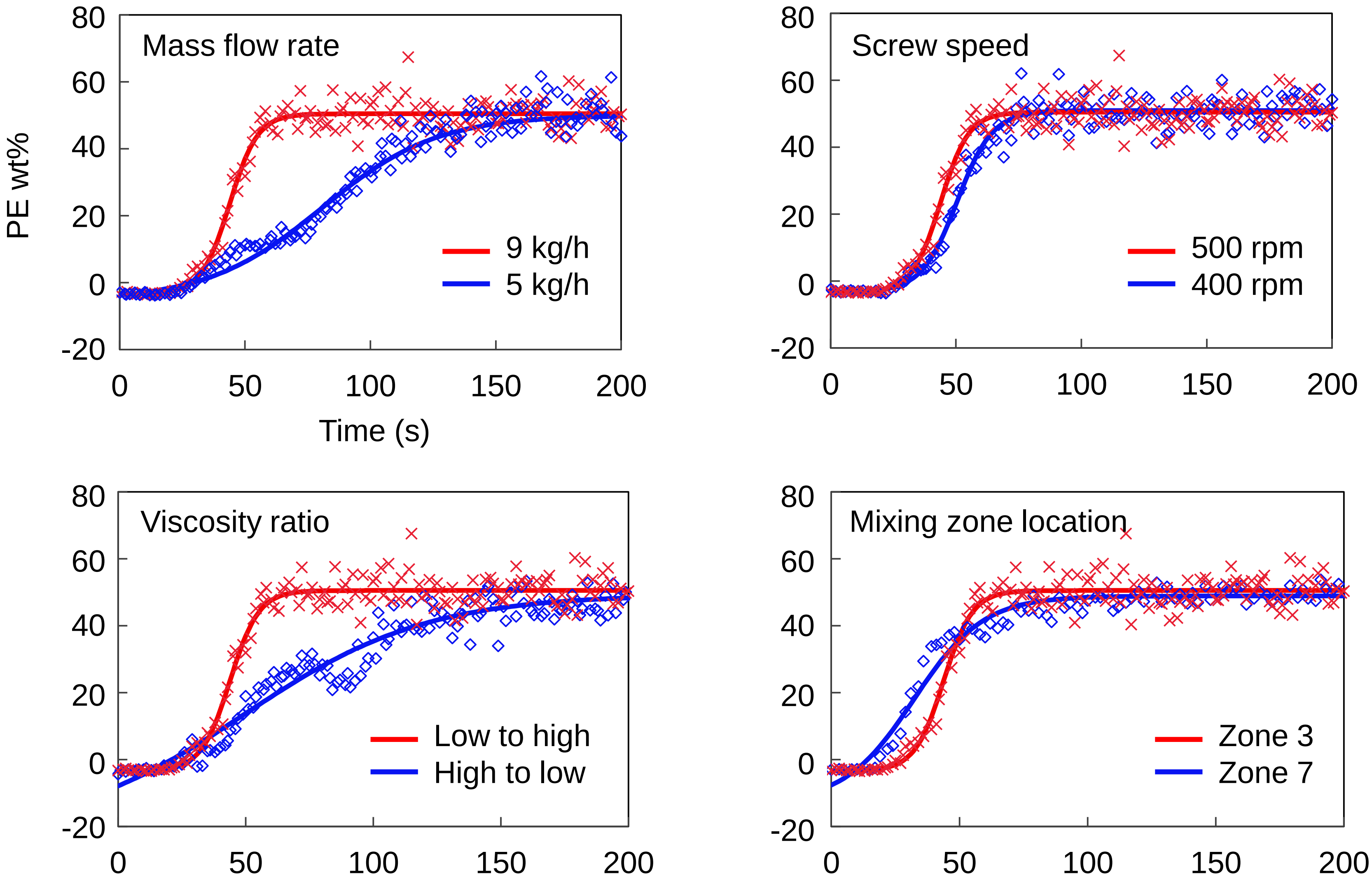
Online Raman method validation

- Collect extrudate sample every 30 s
- Measure the sample composition using offline ATR-FTIR
- Agreement with online Raman results



TSE, 4.5 kg/h, 500 rpm, LLDPE 2045G/PS 685D (50/50) → 100% LLDPE 2045G
Wang et al., *ANTEC Papers*, **2016**

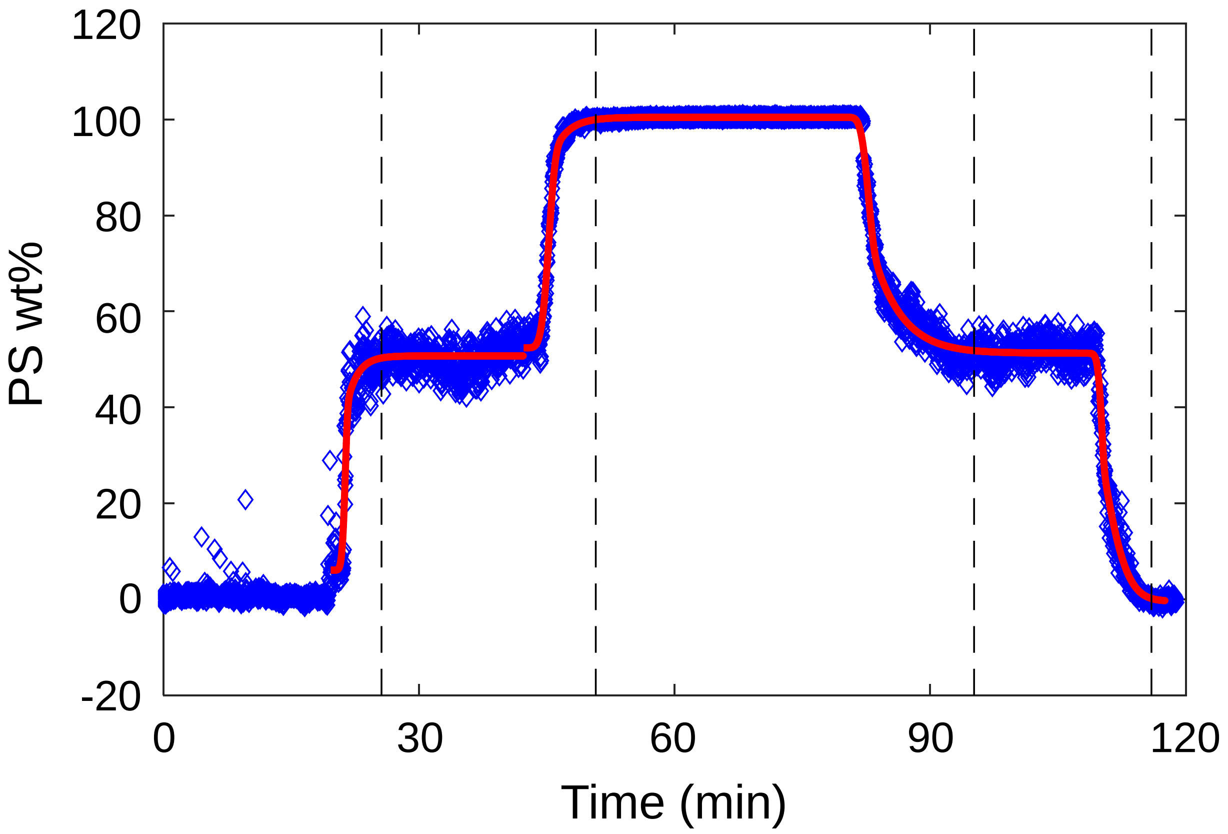
TSE results: Changeover times 1 – 3 min



Wang et al., *ANTEC Papers*, **2016**

Single-screw extruder (SSE) experiments

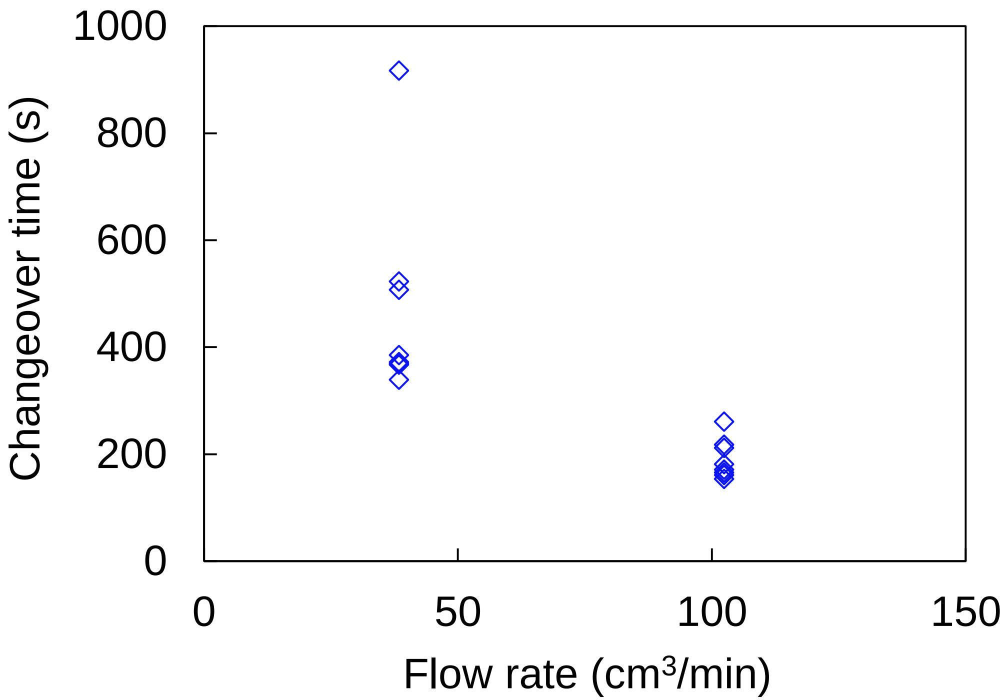
- MATLAB online fitting and analysis
- Double Weibull curve fit to reduce noise
- Changeover time criteria: 99% of change complete



SSE, 4 lb/h, LLDPE 2247G and PS 685D

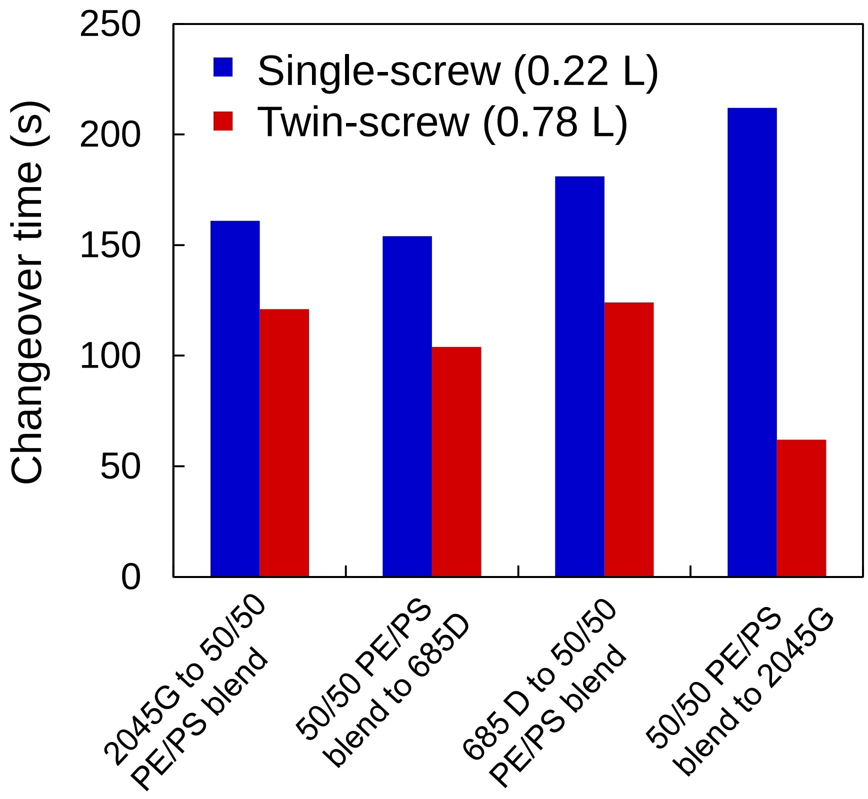
SSE results: Changeover times 2.5 – 15 min

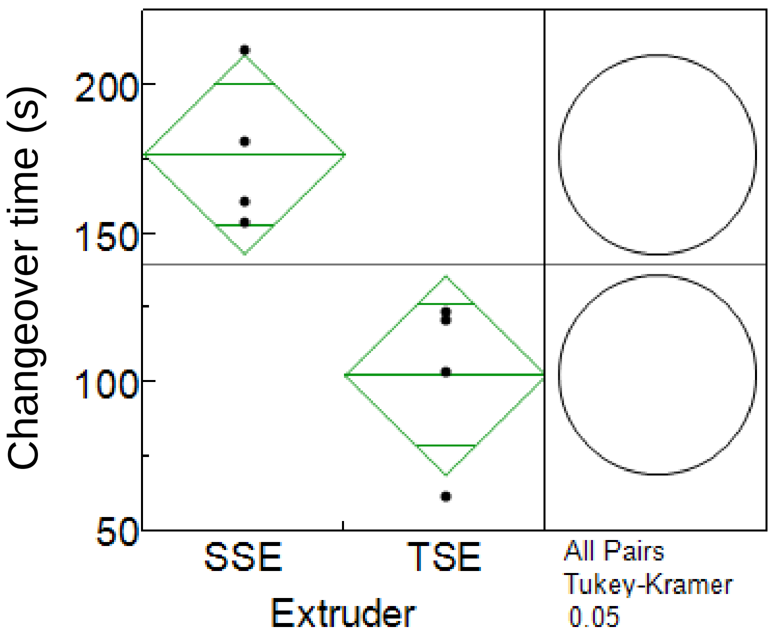
- Increasing flow rate decreases changeover time
- Effects of viscosity ratio less pronounced, but weak, opposite effect of TSE
  - Stationary boundary layer (Kim et al., *SPE Polyolefins*, 2017)



Comparison of changeover times

- Changeover times at same flow rate, materials
- TSE changeover is more rapid
- Hypothesis: self-wiping capability of TSE leads to shorter tail of distribution

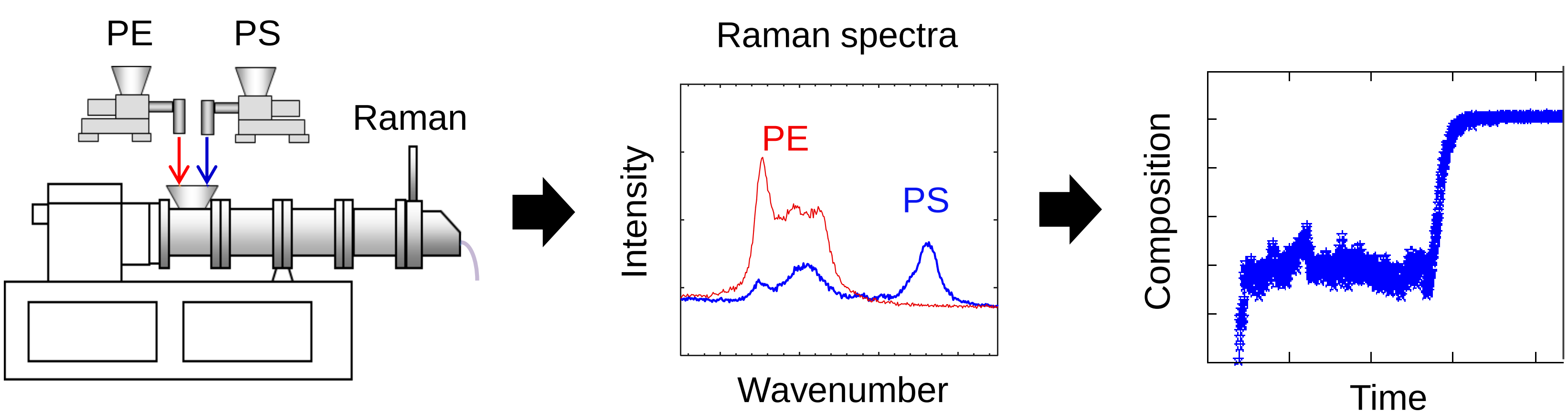




SSE: Double Weibull fit, 99% change criteria
TSE: Sigmoidal fit, 0.1 wt% change criteria

Conclusions

- Increase throughput to decrease changeover time
- Online Raman exit composition validated
- TSE changes formulation more rapidly than SSE



TSE: 1 – 3 min
SSE: 2.5 – 15 min

Extra slides

Offline IR on Sample Composition

PE/PS blends prepared using Haake mixer for calibration

Sample	Actual		CLS response		CLS predicted	
	PE	PS	CLS PE	CLS PS	PE	PS
1	100%	0%	1	0	100.00 %	0.00%
2	95%	5%	1.721	0.080	95.27%	4.73%
3	90%	10%	1.240	0.117	90.84%	9.16%
4	50%	50%	0.489	0.458	49.89%	50.11%
5	10%	90%	0.178	1.334	11.04%	88.96%
6	5%	95%	0.083	0.908	7.84%	92.16%
						100.00