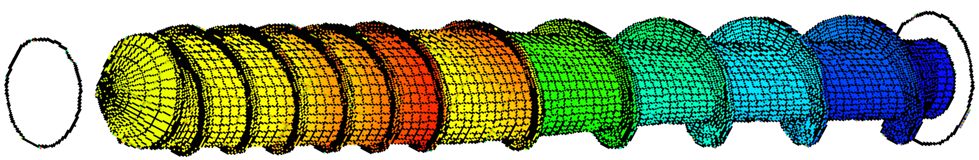
Screw extrusion rheometer

By

Apisit Kositchaiyong

id 52500605



MTT 651 : Polymer rheology (Rheometer)

24 November 2009

Rheometer for highly viscous molten polymer

Piston-extrusion

Stress-controlled
- Melt flow indexers
- Capillary or circular die
- Slit die

Rate-controlled
- Capillary or circular die
- Slit die

Screw-extrusion

Rate-controlled
- Capillary or circular die
- Slit die

Operation methods
- Off-line
- In-line
- On-line

Rotational viscometers

Cone and plate viscometers

Parallel plate viscometers

Concentric cylinder viscometers

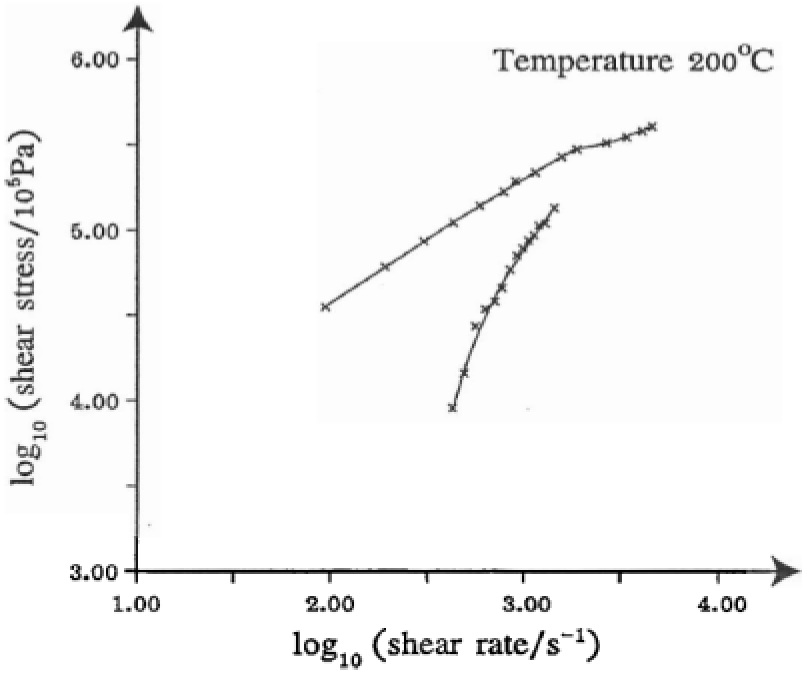
Mooney viscometers

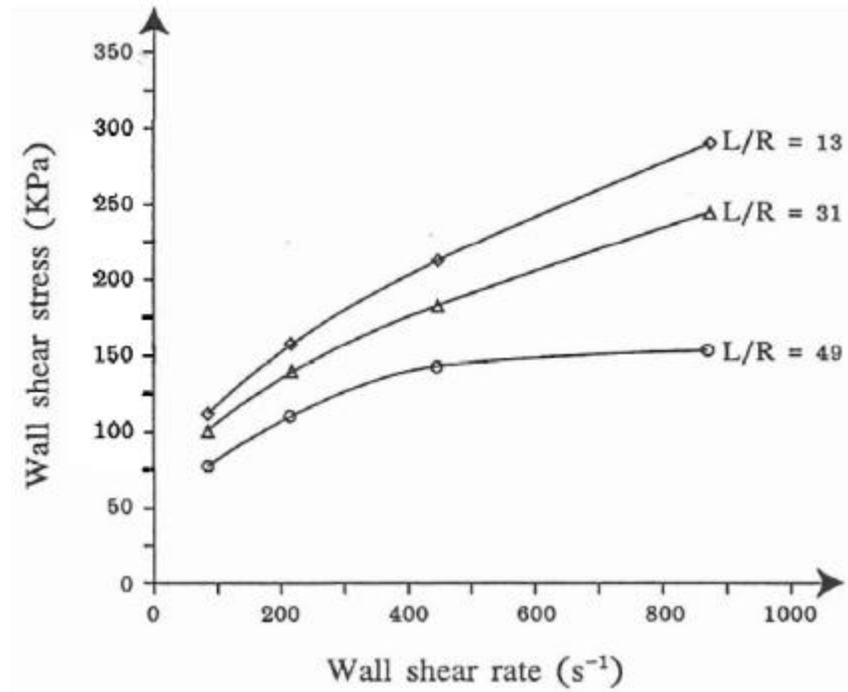
Falling object viscometers

Falling ball viscometers

Rolling ball viscometers

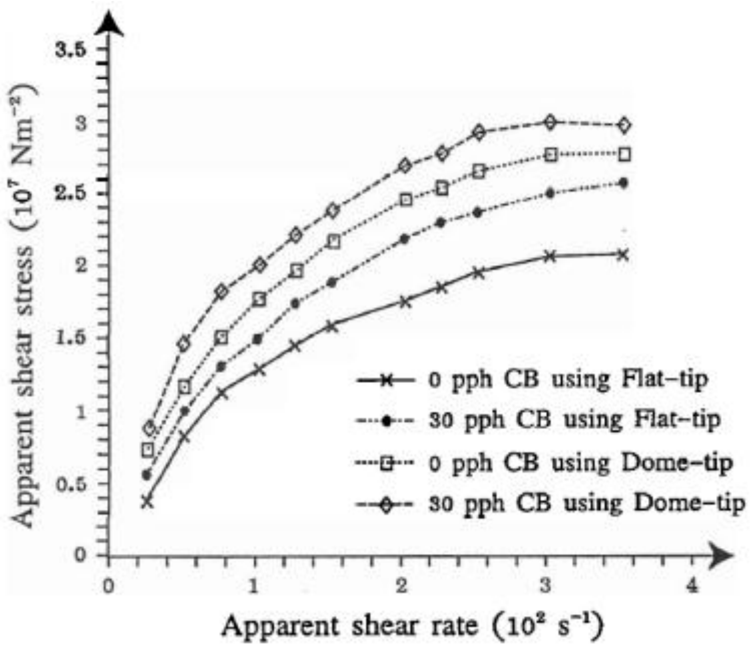
Some errors occur in general rheometers.



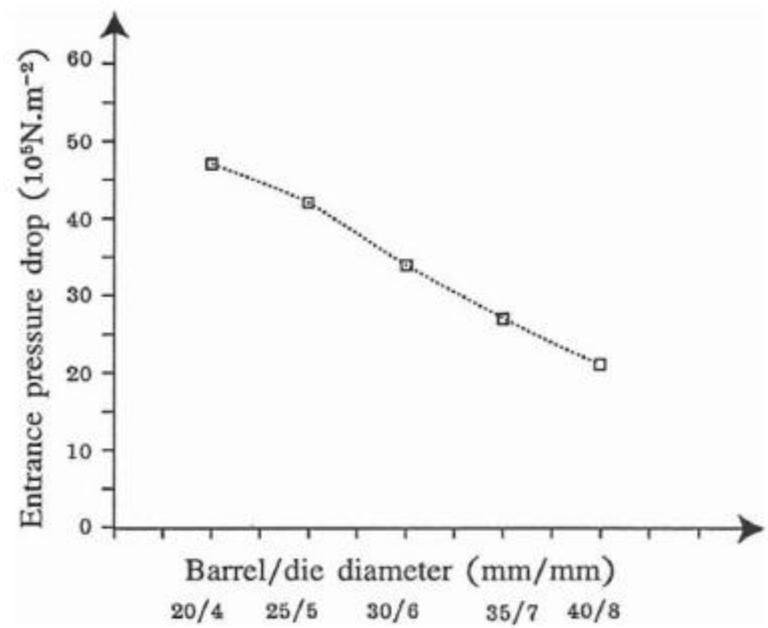


$$\tau = \frac{\Delta P\, R}{2L} \qquad \dot{\gamma}_{\mathrm{a}} = \frac{4Q}{\pi R^3}$$

Shear rate (s^{-1})	Shear stress (10^3 Nm^{-2})		
	Data set#1	Data set#2	Data set#3
4	27	30	26
10	36	40	40
18	55	58	57
36	72	74	73
91	121	119	120
180	153	152	154



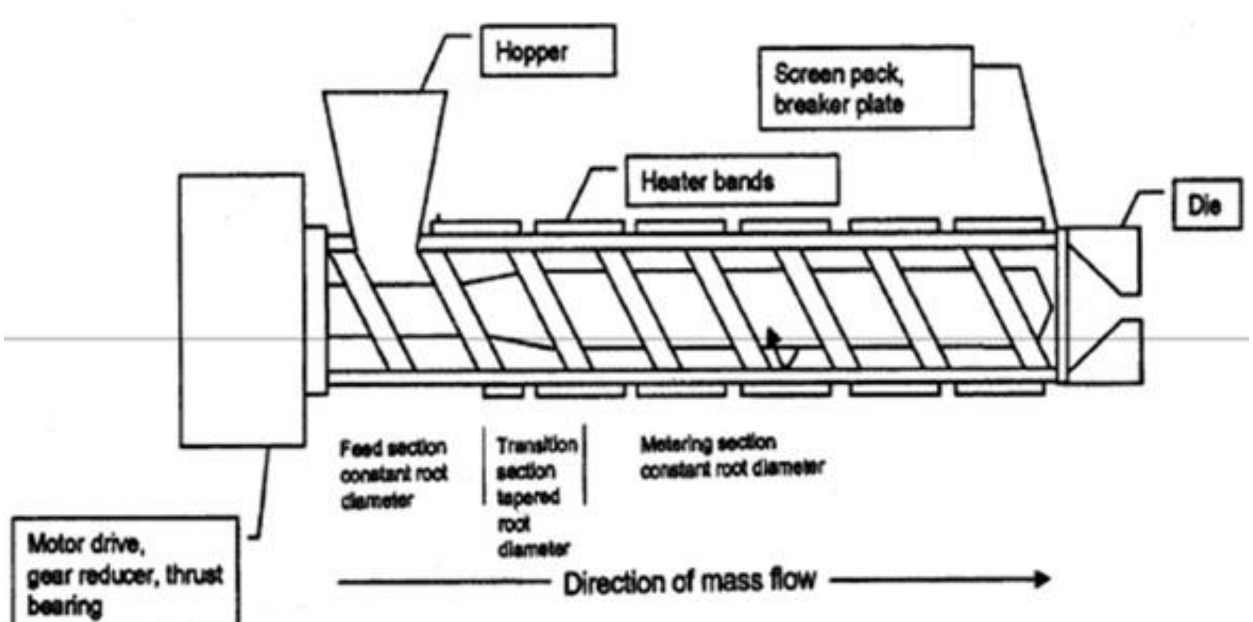
[Sombatsompop, N ; 2001]



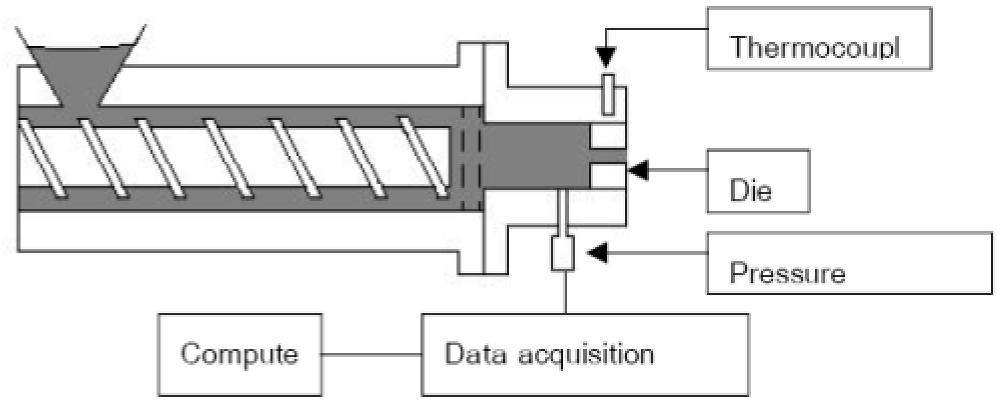
[Sombatsompop, N & Dangtungee ; 2001]

Classification of S.E.R.

- Off-line S.E.R.
- In-line S.E.R.
- On-line S.E.R.



Off-line rheometer



Generally off-line rheometers are used to determine the primary flow properties of the polymer under a laboratory scale. The advantage of off-line rheometer is that the data can be obtained before the real production, but the drawback is then might be a discrepancy in measurements because material measured is not in the real processes.

Off-line rheometer

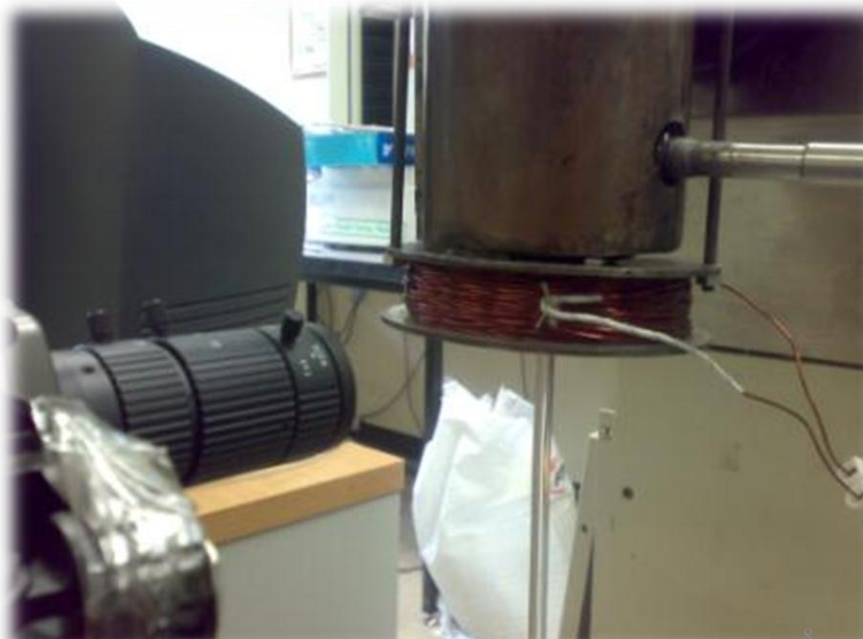
Melt Flow Indexer

Capillary Rheometers

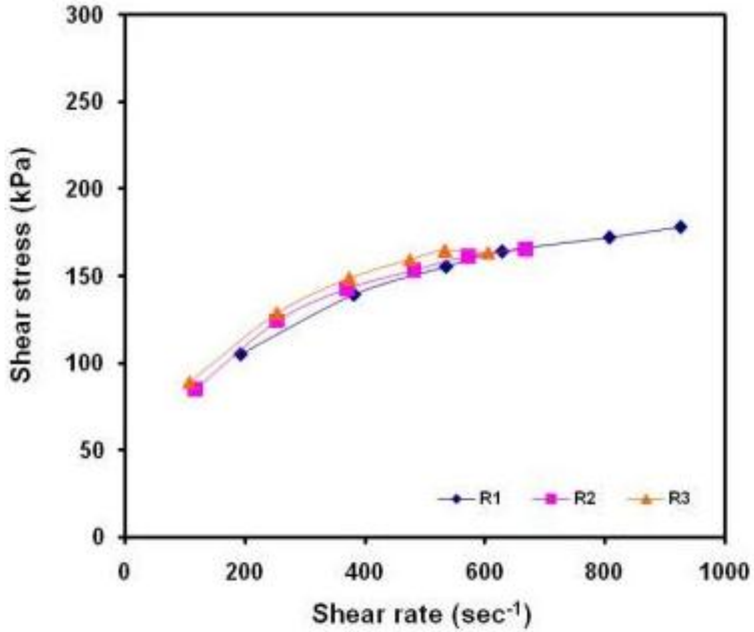
Single Screw Rheometers

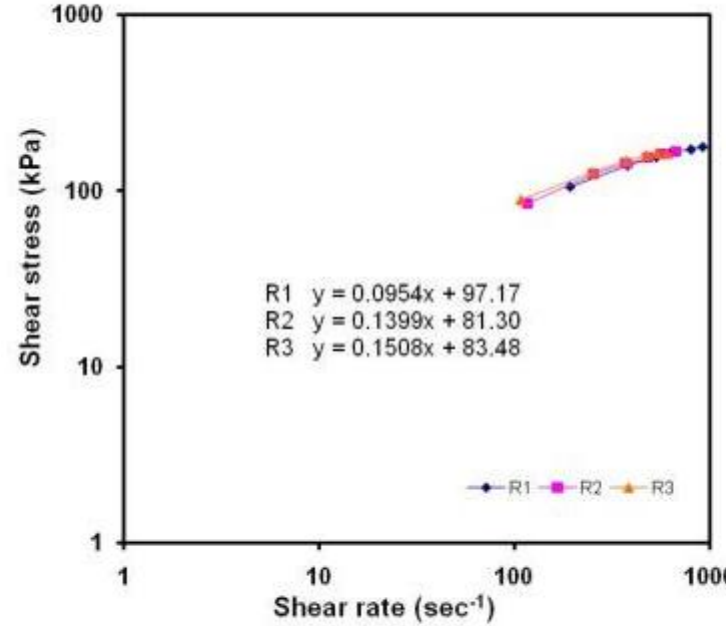
http://www.celsum.com/LMI%204000%20Melt%20Flow%20Indexer.htm (18 Nov 09)



Off-line rheometer





$$\tau = \frac{RP}{2L}$$

$$\dot{\gamma} = \frac{4Q}{\pi R^3}$$

$$\tau = k\,\dot{\gamma}^{n}$$

$$\log \tau = \log k + n \log \dot{\gamma}$$

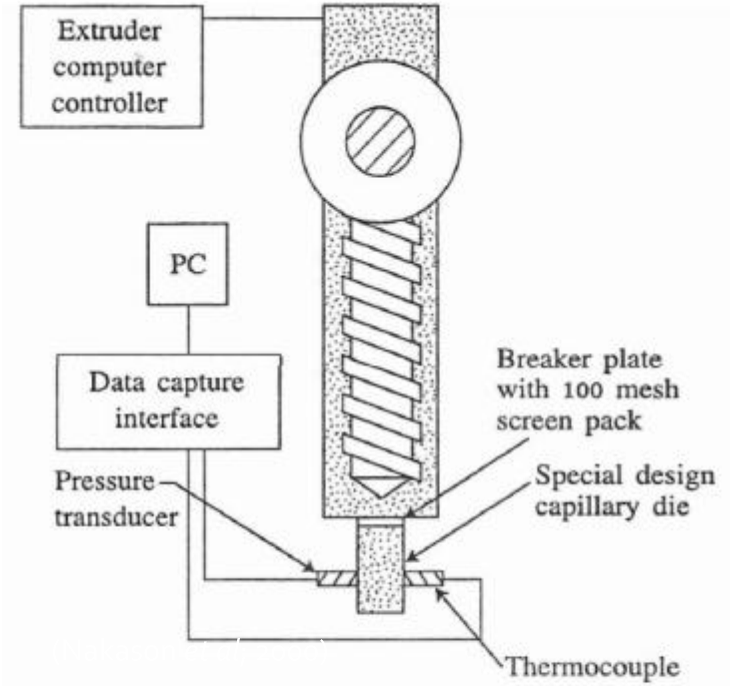
$$MFI = 10 \times 60 \times \dot{w} = Q\rho$$

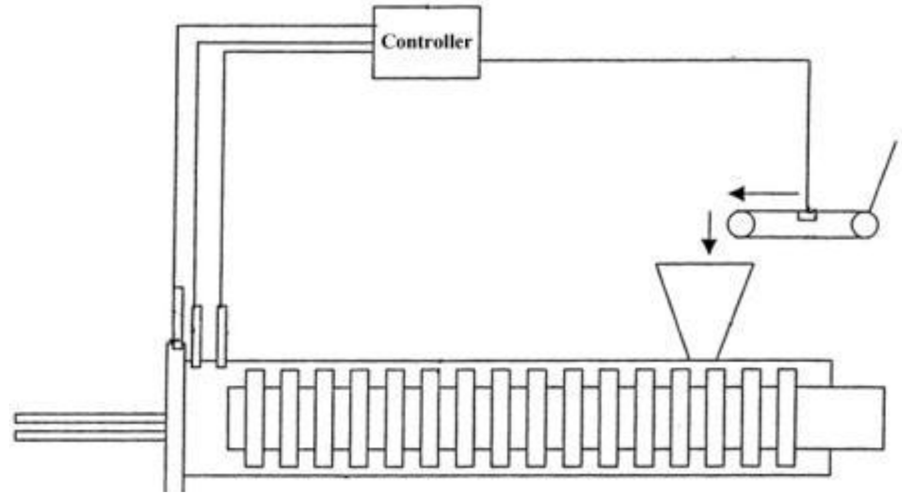
where $\dot{w}$ = weight rate of flow (g/s)

$$Q = \frac{MFI}{600\,\rho}$$

$$\dot{\gamma} = \frac{4\left[\dfrac{MFI}{600\,\rho}\right]}{\pi R^3}$$

In-line rheometer





In-line rheometer is designed to measure the rheological properties of the polymer melt within the processes. The polymer melt property (also pressure and flow rate) is measured directly in the barrel. The flow properties of the polymer melt measurement in this technique are highly accurate because of the polymer melt were produced from the real processes. However, the polymer melt flowing in process were interrupted by the connecting apparatus of the in-line rheometer that affect the polymer product. Furthermore, the in-line rheometer are very complicated in design and difficult to maintain.

(Sombatsompop N., 2003, "Polymer Rheology and applications," KMUTT, Bangkok.
Han C.D., 1976, "Rheology in Polymer Processing," Academic Press, New York.
McBrearty, M. 2000, "In-Line Rheometer for Polymer Melts, Compounds and Solutions," **SPE ANTEC**, pp. 993-997.)

In-line rheometer

ViscoSensor

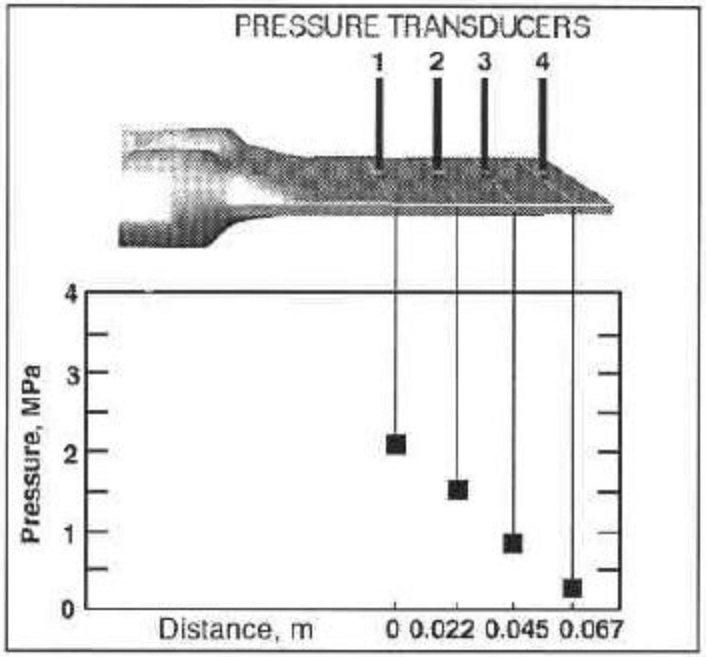
The world's smallest in-line polymer melt rheology instrument, measuring only 635 mm (25 inches) in length by 254 mm (10 inches) in width, the **ViscoSensor** is extremely easy to install, calibrate and operate, making it the most cost-effective in-line sensor on the market. The **ViscoSensor**'s zero discharge system returns the polymer back to the process, eliminating material waste. The **ViscoSensor** can be used to generate shear rate vs. viscosity data or continuous ASTM melt control tool that can be used for product quality and consistency

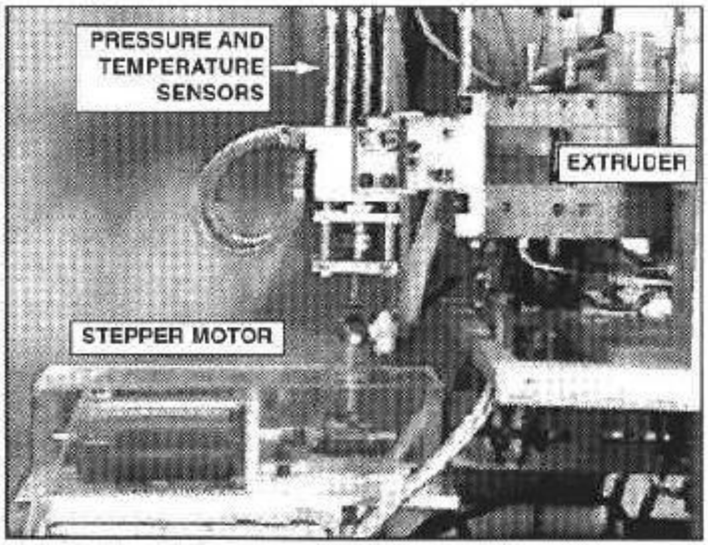
http://www.celsum.com/Viscosensor.htm (18Nov 09)

Features:

- **Attaches to the process using a standard M18 port**
- **Online viscosity or melt index monitoring**
- **No waste stream**
- **Online ASTM D1238 Melt Flow Rate**
- **Apparent Viscosity and Shear Rate available**
- **Capillary is easy to replace**

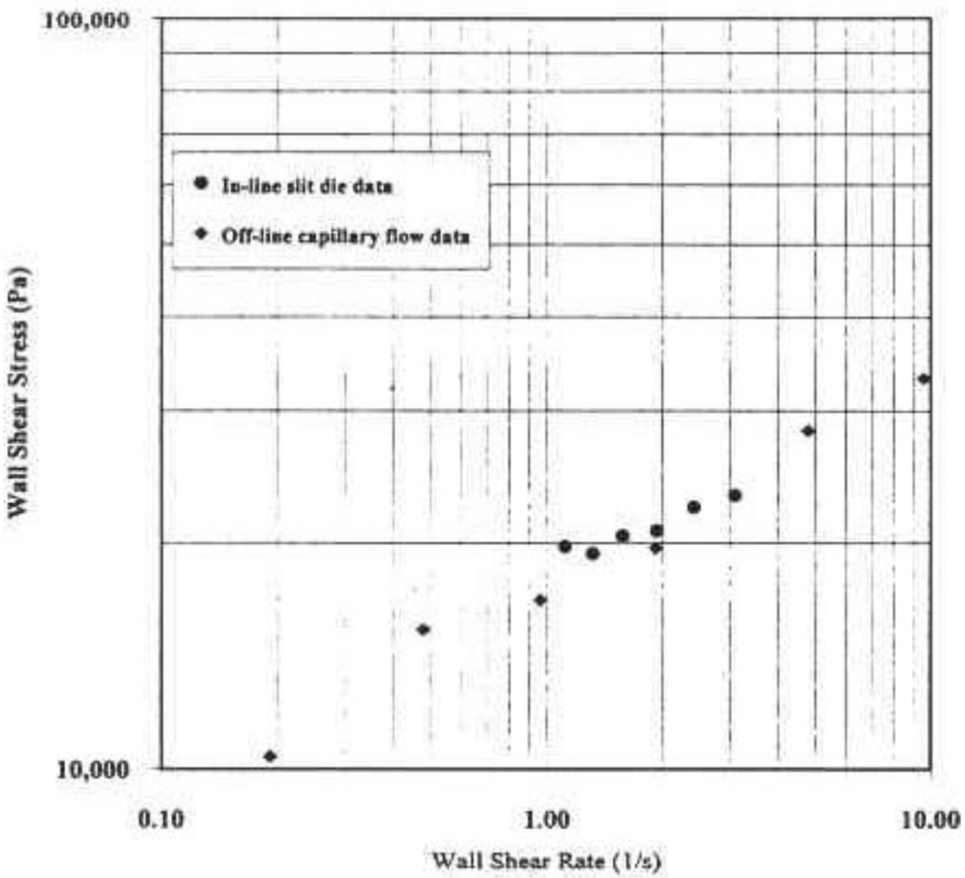
An Adjustable Gap In-Line Rheometer



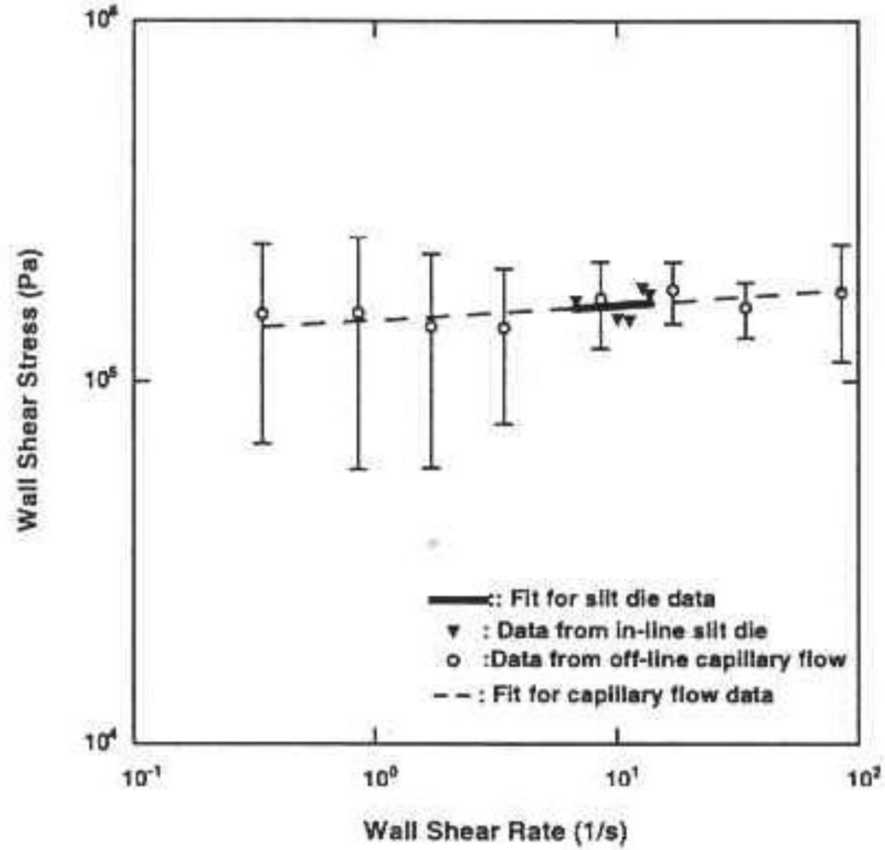


(D. M. Kalyon, H. Gokturk and I. Boz; http://www.hfmi.stevens.edu/publications/133.PDF (23 Nov 09)

Flow property of TPE by in-line rheometer



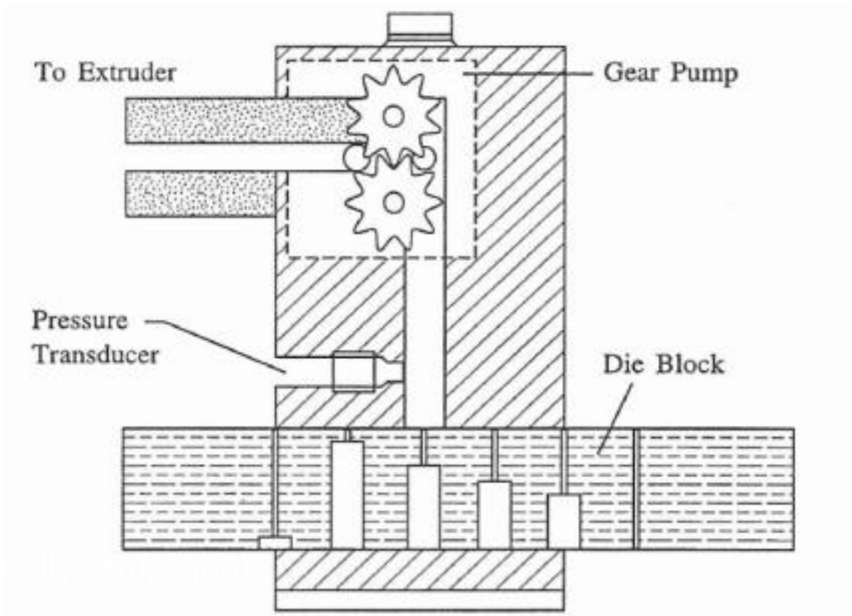
Comparison of data collected with in-line rheometer and off-line capilary flow data for a plasticized TPE at a plasticizer/TPE ratio of 0.275

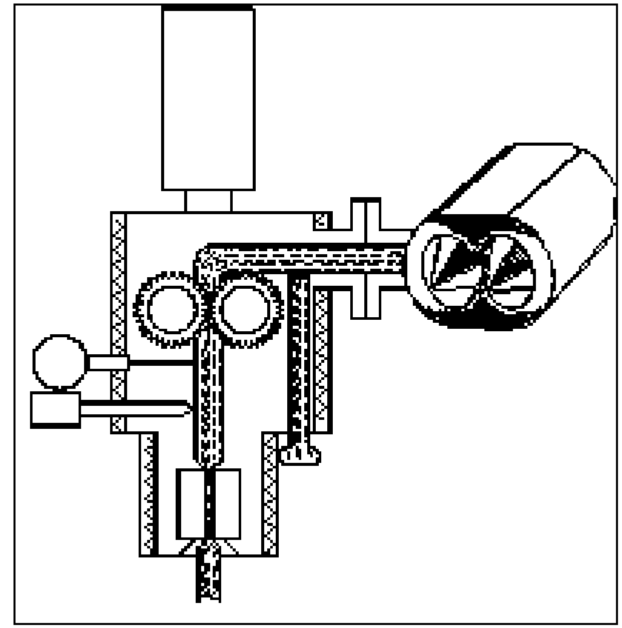


Comparison of data collected with in-line rheometer and off-line capilary flow data for a filled elastomer

(D. M. Kalyon, H. Gokturk and I. Boz; http://www.hfmi.stevens.edu/publications/133.PDF (23 Nov 09)

On-line rheometer

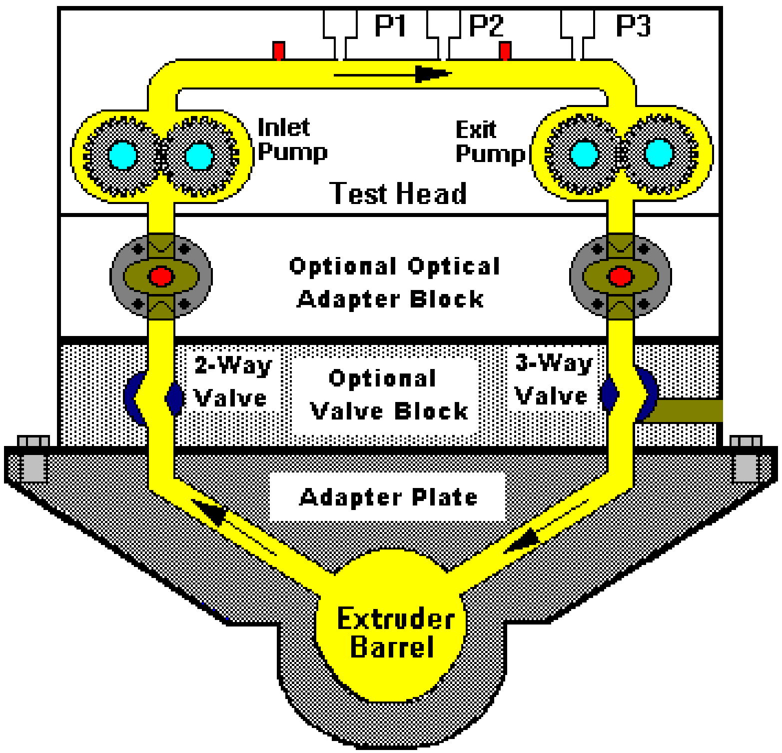




The principle of on-line rheometer is to measure the rheological properties of the polymer melt during the processes. The polymer melt is transferred from the barrel of the extruder machine to the on-line rheometer unit by gear pump unit, and the pressure drop of the melt were measured. The shear stress is calculated from the pressure drop measured at the die entrance region, while the shear rate can be calculated from the rotating speed of the gear pump unit. The flow properties of the polymer melt measurement in this technique are closely accurate, because of the polymer melt produced from the real processes. However, the polymer melt flowing in process were interrupted by the connecting apparatus of the on-line rheometer that affect on the polymer product.

(Sombatsompop N., 2003, "Polymer Rheology and applications," KMUTT, Bangkok.)

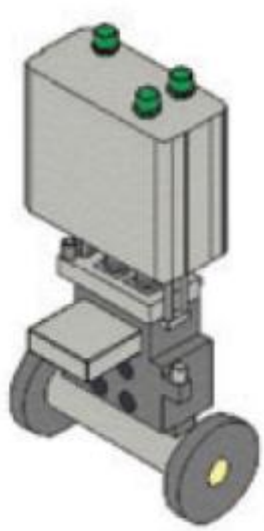
On-line rheometer

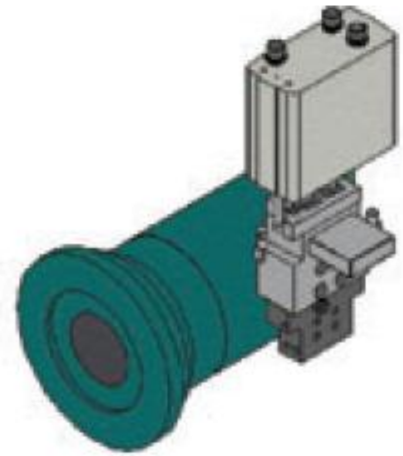


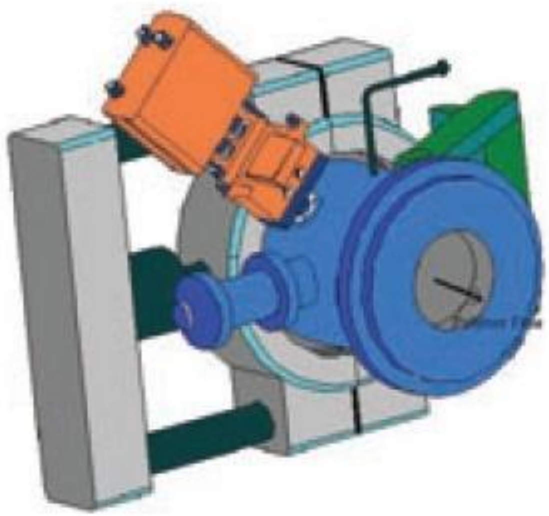
Goettfert online capillary rheometer that is used in polymer production plants to continously monitor the melt properties of the polymer being produced. It is used for online Quality Control and Monitoring

http://www.polymers-center.org/products/testinfo4.htm (18 Nov 09)

HAAKE PCR 620 Online Rheometer







On-line rheometer

CMR IV Continuous Melt Rheometer

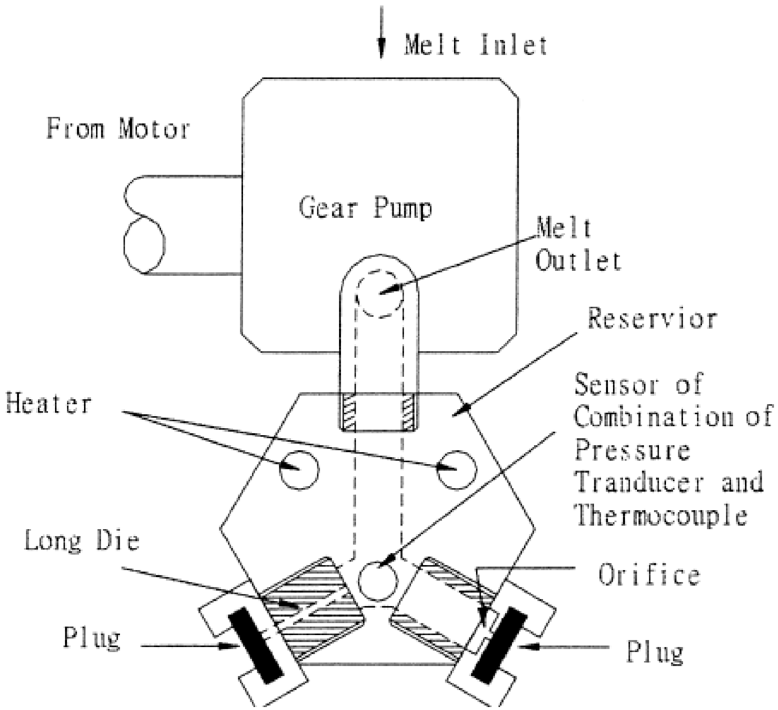
Mono Online Rheometer
Type MOR-R (round) MOR-F (flat)

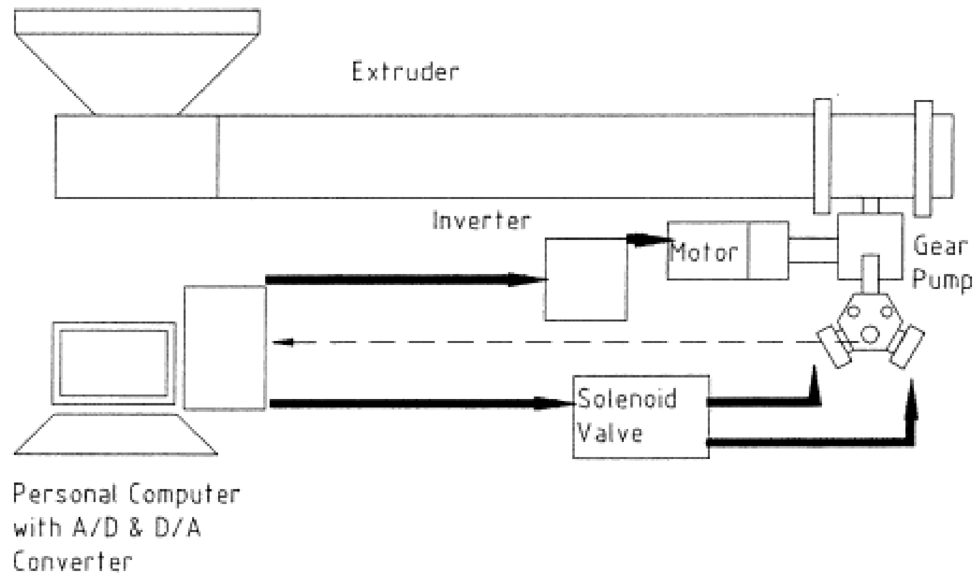
http://www.celsum.com/CMR%20IV%20Continuous%20Melt%20Rheometer.htm (18 Nov 09)

http://www.directindustry.com/prod/dr-collin-gmbh/laboratory-roller-mill-50066-360946.html#prod_360946 (18 Nov 09)

On-line rheometer

Dual capillary rheometer





Rabinowitsch correction.

$$\dot{\gamma}_{\mathrm{a}}^{*} = \dot{\gamma}_{\mathrm{a}} \cdot \left(\frac{3n+1}{4n}\right),$$

Chiu and Pong solved the Bagley and Rabitnowitsch correction using dual capillary on-line rheometer.

(Chiu, S.H. and Pong, S.H.; 1999)

$$\tau = \frac{RP}{2L}$$

$$\dot{\gamma} = \frac{4Q}{\pi R^3}$$

$$\eta = \frac{\tau}{\dot{\gamma}}$$

$$\tau = k\dot{\gamma}^n$$

$$\log \tau = \log k + n \log \dot{\gamma}$$

$$n = \frac{d \log \tau}{d \log \dot{\gamma}}$$

Bagley correction

$$\tau^* = \frac{R(P - P_0)}{2L}$$

Rabinowitsch correction

$$\dot{\gamma}^* = \dot{\gamma}\left(\frac{3n+1}{4n}\right)$$

$$\eta = \frac{\tau^*}{\gamma^*}$$

$$Q = C_1 + C_2P + C_3N + C_4NP + C_5N^2 + C_6PN^2,$$

fficient	C_1	C_2	C_3	C_4	C_5	C_6
Data	0.097328	−0.007413	0.014097	0.000045	0.000014	0.0

P_o = Pressure drop through an orifice die (die with L/R <1) of the same diameter at the same flow rate

Q = Volumetric flow rate

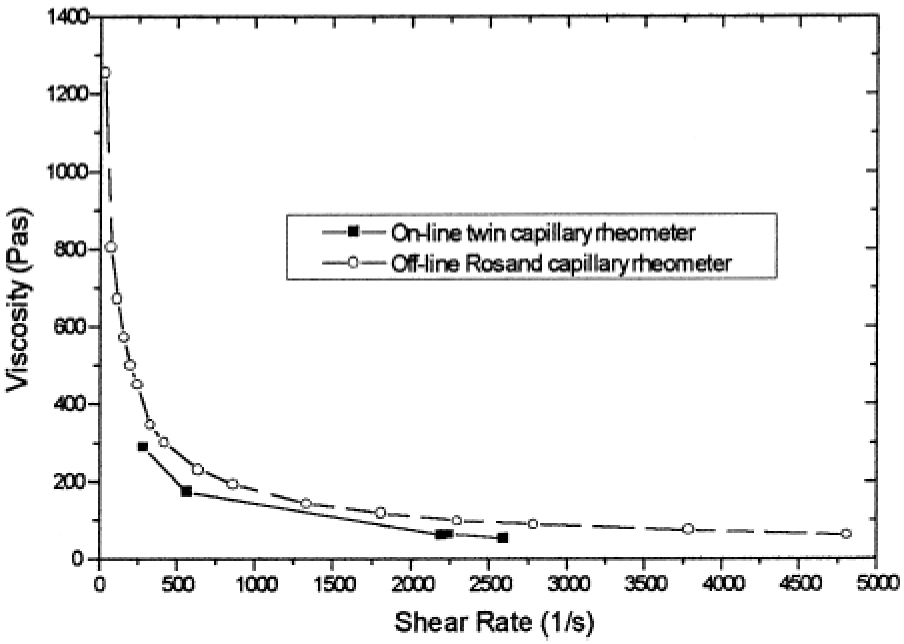
N = Pump speed

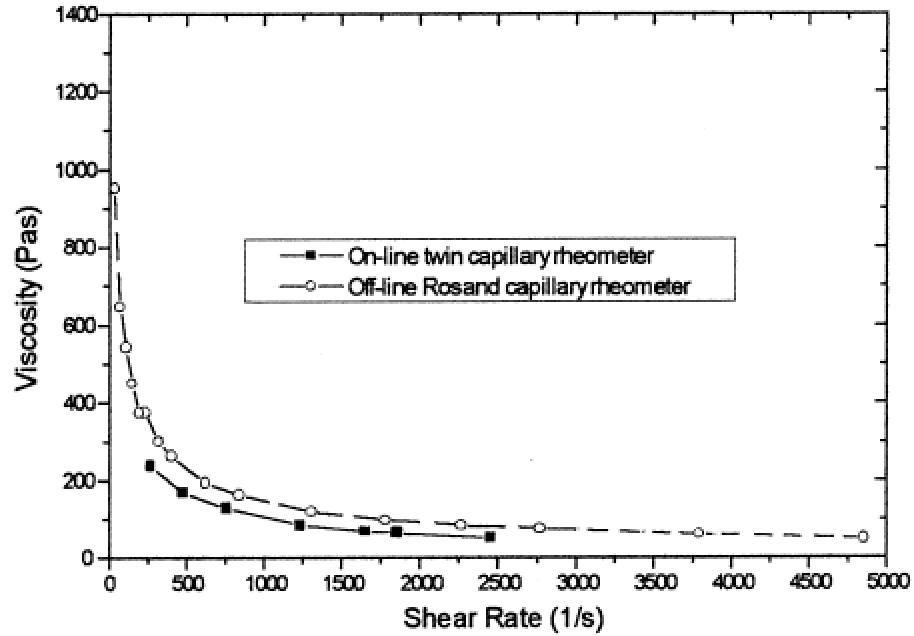
P = Capillary pressure drop

C_n = Coefficient at n is a positive integer

(Chiu, S.H. and Pong, S.H.; 1999)

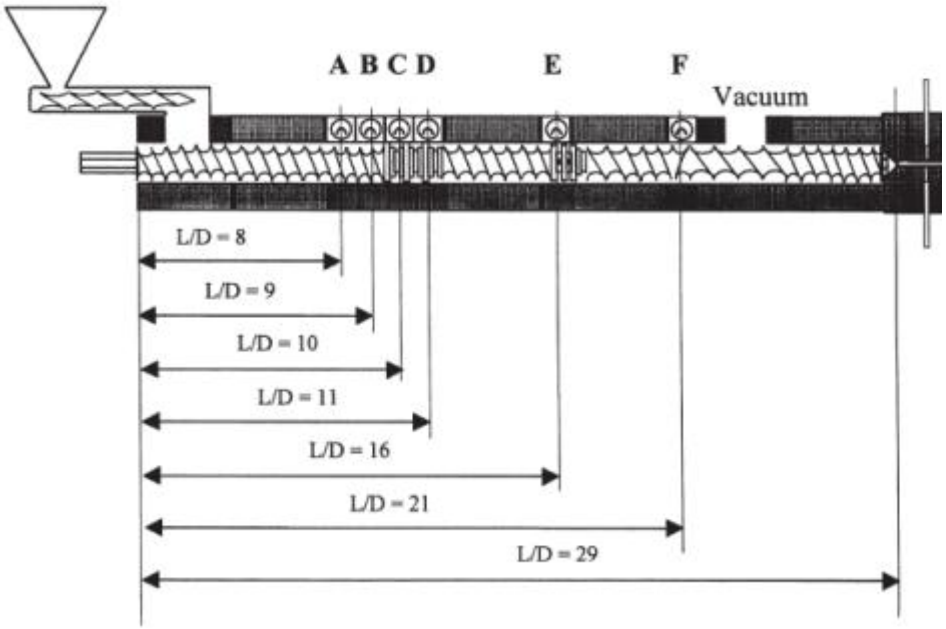
Viscosity of LDPE 170ºC and 190ºC

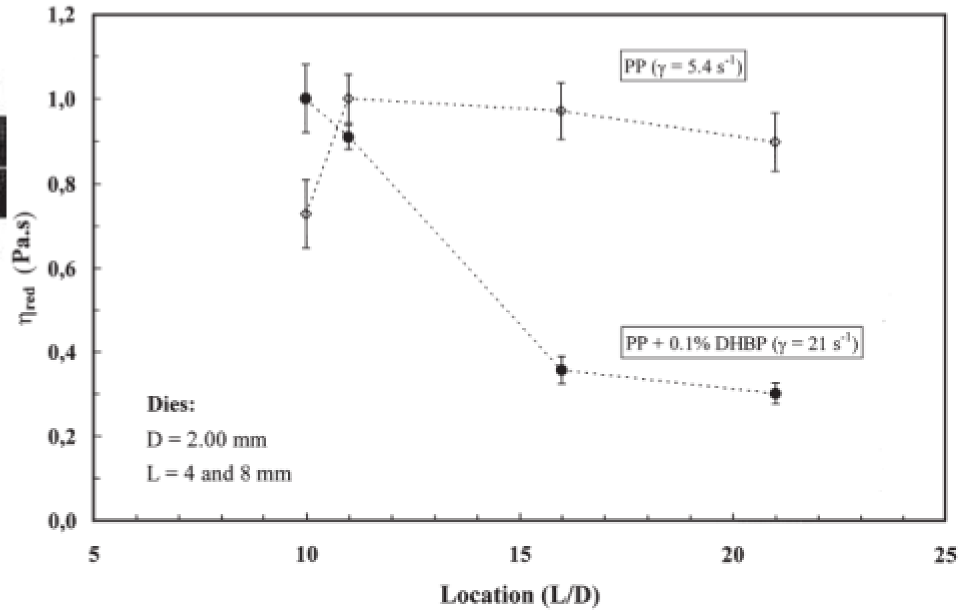




(Chiu, S.H. and Pong, S.H.; 1999)

Monitoring of peroxide-induced thermal degradation of polypropylene





Location A were not possible, since the screws were only partially filled
Location B, the screws were already filled but the material was mostly solid and measurements were also impossible.
Location C, which is axially 34 mm apart from location B, the material is fully melted due to the smearing action of the kneading blocks.
Location D-E, the reaction appears to proceed and then the viscosity remaining constant .

(J.A. Covas *et al*; 2000)

Comparisons between off-line, in-line and on-line rheometers

Contents	Off-line	In-line	On-line
Flow pattern	Lamina flow	Turbulent flow	Turbulent flow
Temperature gradient	Isothermal	Non-isothermal	Non-isothermal
Melt mechanism	Molecular thermal diffusion or sintering process	Shear deformation and shear heating process	Shear deformation and shear heating process
Assumption correction	Agree	Disagree	Disagree
Translation of result	Shear stress vs. shear rate	Pressure vs. output rate	Pressure vs. output rate
Applications	For comparable (Need up-scale)	Production value (Simultaneously applicable)	Production value (Simultaneously applicable)
Mixing data	No	Yes	Yes
Cost	Lower	Higher	Higher
Processing disturbance	No	Yes	Yes
Instrument	Simple	More complex	More complex
Material amount for test	Small	More	More
Time for test	More	Less	Less
Errors	Many sources ex. Human error, upscale error, time error	Flowing melt can be disturbed by attached instrument.	Melt property might be changed due to transferring of melt to measurement section.