# Viscometry Constants for 1,4-Polybutadiene in Tetralin at 135°C

For linear-chain polymers,

$$[\eta] = K * (M_v)^a \quad (1)$$

where $[\eta]$ is intrinsic viscosity, $K$ and $a$ are Mark–Houwink parameters for a given polymer in a specified solvent at a specified temperature, and $M_v$ is the viscosity average molecular weight. Thus, if $[\eta]$, $K$, and $a$ are known, $M_v$ can be calculated. Or if $[\eta]$ is measured for a series of standards with known molecular weights $M$, then $a$ and log $K$ are obtained from a plot of log $[\eta]$ vs. log $M$.

During the course of a research program on blends of crystallizable polybutadiene (PBD) isomers,[1,2] we needed to determine the molecular weight of a *trans*-1,4-polybutadiene sample. Gel permeation chromatography (GPC) of the *trans*-1,4-PBD in 140°C tetralin was unsuccessful due to extensive polymer degradation during testing. Therefore, we obtained Mark–Houwink constants for a series of 1,4 PBD (mixed *cis/trans*) standards of known molecular weight and low polydispersities. The constants were determined using solutions of PBD in tetralin at 135°C, and then we obtained the $M_v$ of the *trans*-1,4-PBD sample.

The series of 1,4-PBD standards had molecular weights of 5000, 23,000, 150,000, and 240,000 g/mol (American Polymer Standards Corporation, Mentor, OH). The standards were reported to have polydispersities of 1.1–1.3 and microstructures with approximately 42% *cis*-1,4, 50% *trans* 1,4, and 8% 1,2 repeat units.

The intrinsic viscosity $[\eta]$ is the $y$-intercept on a plot of $\eta_{sp}/c$ or $\ln(\eta_r)/c$ as a function of $c$ (concentration), where $\eta_r = \eta/\eta_0$ is the relative viscosity and $\eta_{sp} = (\eta - \eta_0)/\eta_0 = \eta_r - 1$ is the specific viscosity; in these relationships, $\eta$ is the sample viscosity and $\eta_0$ is the viscosity of the solvent.[3] It is usually reasonable to approximate the quantity $\eta/\eta_0$ by $t/t_0$, where $t$ is the time for a polymer solution to pass between two marks on an appropriate viscometer and $t_0$ is the time for pure solvent to pass between the same marks. This approximation breaks down at low values of $t$, where a kinetic energy correction is required.[3,4] It is also possible to use a series of viscometers to obtain data at various flow (shear) rates and thereby extrapolate to zero shear rate conditions. We report data here which are uncorrected for the effects of kinetic energy and finite shear rate.

A Cannon-Fenske viscometer (size 150) was used for all of our viscometry tests. The viscometer was placed in a stirred oil bath at 135 ± 2°C. Sample solutions were prepared and tested in 10 mL tetralin. Immediately prior to the test, solutions were mixed at 135°C for at least 30 min. Between runs, the viscometer was rinsed with 10 mL tetralin until $t_0$ was reproducible at 19.7 ± 0.2 s. At least four concentrations were tested for each 1,4-PBD standard, as listed in Table I. The concentrations were selected to give approximately $1.2 < t/t_0 < 2.0$.

The higher molecular weight 1,4-PBD standards (150,000 and 240,000 g/mol) degraded with time in the hot tetralin. The flow times $t$ became progressively shorter as the solutions remained at 135°C over the course of approximately 30 min, even when Irganox 1076 antioxidant (Ciba-Geigy Corporation, Hawthorne, NY) was present in the solution. In order to obtain reliable $K$ and $a$ values, the flow times of each solution were determined for various exposure times in the hot tetralin and then extrapolated back to zero exposure time. We note that *trans*-1,4-PBD also showed this time-dependent degradation, but syndiotactic 1,2-PBD samples showed negligible degradation in 135°C tetralin over the course of approximately 30 min.

Figures 1 and 2 are plots of $\eta_{sp}/c$ and $\ln(\eta_r)/c$ as a function of concentration for all of the standards. Figure 3 is the best-fit regression plot of log $[\eta]$ as a function of log $M$. It yields $K$ and $a$ equal to 0.0161 ± 0.0025 mL/g and 0.74, respectively, for analysis based on the $\eta_{sp}$ correlation, and $K$ and $a$ equal to 0.0145 ± 0.0022 mL/g and 0.75 for analysis based on the $\ln(\eta_r)$ correlation. The plotted line on this figure is the average of the two sets of points. In either case, correlation coefficients ($R^2$) are greater than 0.992. Correlation coefficients for determination of $[\eta]$ values in Figures 1 and 2 are not as good, but analysis based on $\eta_{sp}$ gives better correlation coefficients than analysis based on $\ln(\eta_r)$. Our results are summarized in Table II along with literature values of $K$ and $a$ for PBD determined under various other experimental conditions.

**Table I Sample Concentrations**

| $M$ (g/mol) | Concentrations (g/mL) |
|---|---|
| 5000 | 0.0021, 0.0052, 0.0073, 0.0082, 0.0127, and 0.0203 |
| 23,000 | 0.0010, 0.0022, 0.0043, 0.0082, and 0.0124 |
| 150,000 | 0.0010, 0.0025, 0.0039, 0.0052, and 0.0060 |
| 240,000 | 0.0010, 0.0020, 0.0030, and 0.0041 |

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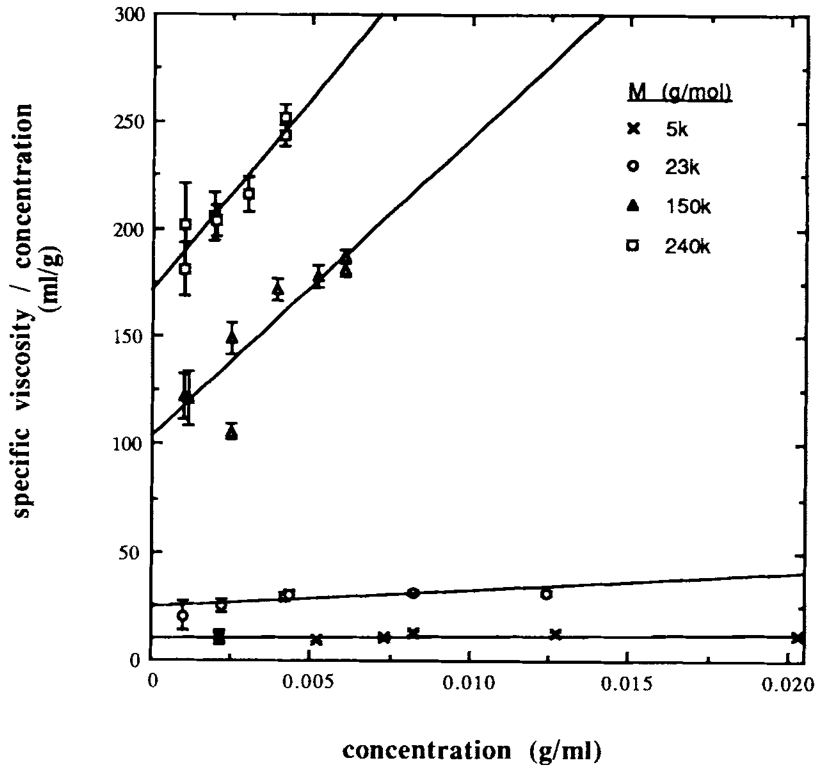


**Figure 1** Plot of $\eta_{sp}/c$ as a function of concentration for all of the standards.

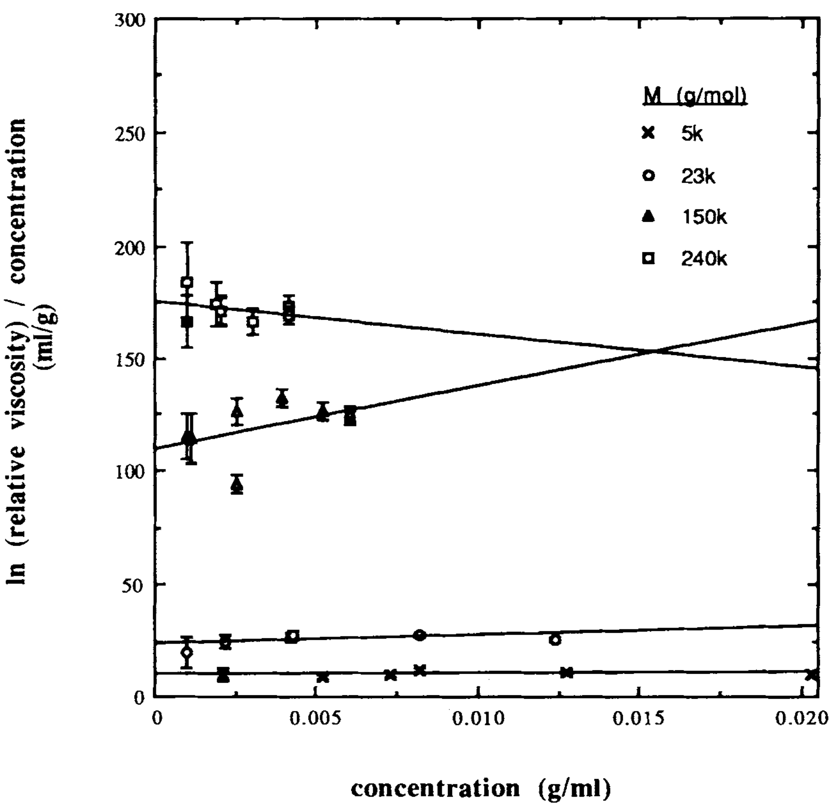


**Figure 2** Plot of $\ln(\eta_r)/c)$ as a function of concentration for all of the standards.

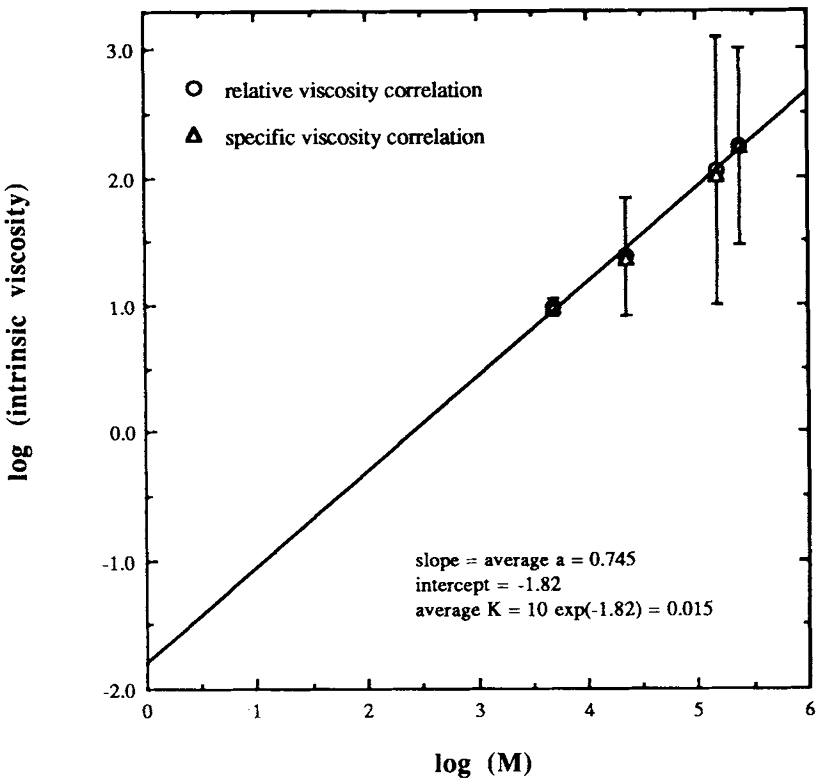


**Figure 3** Best-fit regression plot of log $[\eta]$ as a function of log $M$.

**Table II** ***K*** **and** ***a*** **Values for 1,4-Polybutadiene**

| Composition | Conditions | $K$ (mL/g) | $a$ | Ref. |
|---|---|---|---|---|
| 97% *trans* 1,4, 3% 1,2 | Toluene, 30°C, 50–160 kg/mol | 0.0294 | 0.753 | 5, 6 |
| 55% *trans,* 35% *cis* 1,4, 10% 1,2 | Toluene, 25°C | 0.0142 | 0.80 | 5, 7 |
| 51% *trans,* 43% *cis* 1,4, 6% 1,2 | Toluene, 30°C, 100–250 kg/mol | 0.039 | 0.713 | 5, 8 |
| 5.3% *trans* 1,4, 94.3% 1,2 | Toluene, 25°C | 0.0901 | 0.81 | 5, 9 |
| 50% *trans,* 42% *cis* 1,4, 8% 1,2 | Tetralin, 135°C, 5–240 kg/mol | | | |
| | $\eta_r$ correlation | 0.0145 | 0.75 | |
| | $\eta_{sp}$ correlation | 0.0161 | 0.74 | |

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