Insight — Application Note 2.36

Case Study 2: Averaging and Filtering to Reduce Noise in Dielectric Measurements

Introduction

The response from dielectric sensors can be as little as 0.01 volts amplitude at certain points during cure and often must be distinguished from electrical interference. Data processing may be necessary for dealing with noise, especially for *slope of log(ion viscosity)*, which magnifies noise in *log(ion viscosity)*.

Lambient Technologies' *CureView* data acquisition and analysis software has several options for averaging and filtering the signal, and this application note is a case study in how to reduce noise in dielectric cure monitoring.

Definitions

This application note presents and discusses data for *log(ion viscosity)* and *slope of log(ion viscosity)*, which indicate the state of cure. The plots show characteristic features such as minimum ion viscosity, maximum slope of log(ion viscosity) and the time to a chosen end of cure. For brevity, log(ion viscosity) will be called *log(IV)* and slope of log(ion viscosity) will simply be called *slope*.

Electrical conductivity (σ) has both frequency independent (σ_{DC}) and frequency dependent (σ_{AC}) components. In an oscillating electric field, σ_{DC} arises from the flow of mobile ions while σ_{AC} arises from the rotation of stationary dipoles. These two responses act like electrical elements in parallel and are added together as expressed below:

(eq. 36-1) $$\sigma = \sigma_{DC} + \sigma_{AC} \qquad (\text{ohm}^{-1} - \text{cm}^{-1})$$

Resistivity (ρ) is the inverse of conductivity and is defined as:

(eq. 36-2) $$\rho = 1/\sigma \qquad (\text{ohm-cm})$$

From its relationship to conductivity, resistivity also has both frequency independent (ρ_{DC}) and frequency dependent (ρ_{AC}) components. The amount of polymerization or crosslink density, which are measures of cure state, affect both mechanical viscosity and the movement of ions, and therefore influence ρ_{DC}. As a

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result, the term *Ion Viscosity* was coined to emphasize the relationship between mechanical viscosity and ρ_{DC}. Ion viscosity (*IV*) is defined as:

(eq. 36-3) $$IV = \rho_{DC}$$ (ohm-cm)

Although the strict definition of ion viscosity is frequency independent resistivity, ρ_{DC}, for convenience ion viscosity may also be used to describe resistivity in general, which has both frequency independent (ρ_{DC}) as well as frequency dependent (ρ_{AC}) components. *Note, however, that cure state and mechanical viscosity relate best to frequency independent resistivity, ρ_{DC}, which is true ion viscosity.*

Examining the raw data

Data should first be examined without numerical processing to see the actual results, including noise. To see or change the filtering and averaging parameters, select **Edit** from CureView's main menu bar, then select **Data Parameters** from the dropdown menu. Select the **Filter/Average** tab as shown in Figure 36-1.

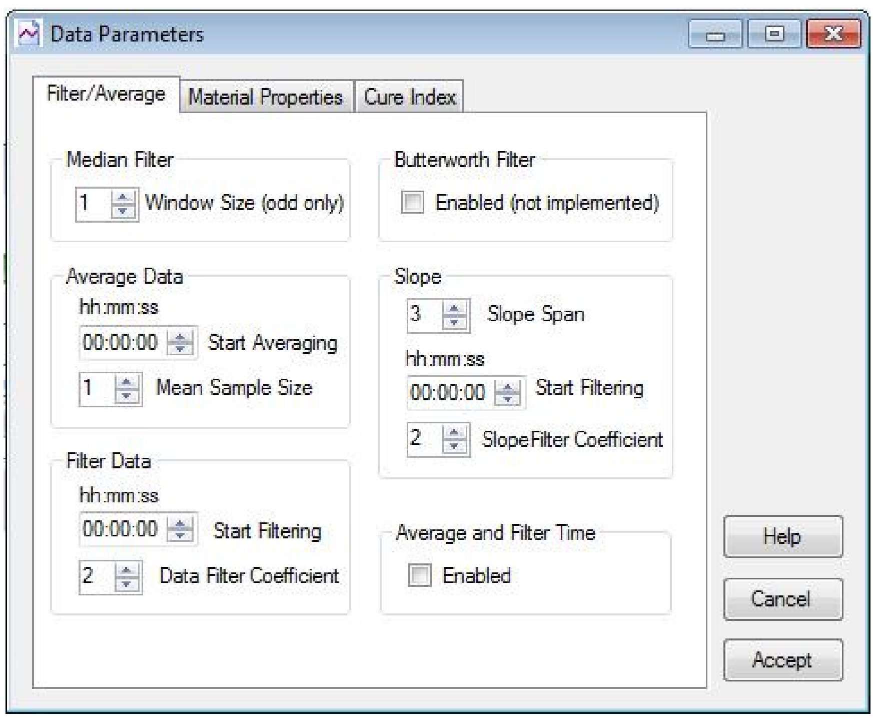

Figure 36-1
Filtering and averaging parameter window

Table 36-1 lists recommended values for initial analysis and viewing of raw dielectric data.

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Table 36-1
Recommended initial noise reduction parameters

Median filter	1	"1" disables median filter
Sample size	1	Average using one data point
Slope span	8	Typical initial value for calculating slope
Data filter coefficient	0	"0" disables filtering of data
Slope filter coefficient	0	"0" disables filtering of *slope*

Figure 36-2 is an example, processed with the parameters of Table 36-1, showing raw data for *log(IV)* during the cure of an epoxy resin. *Slope* is not shown for clarity.

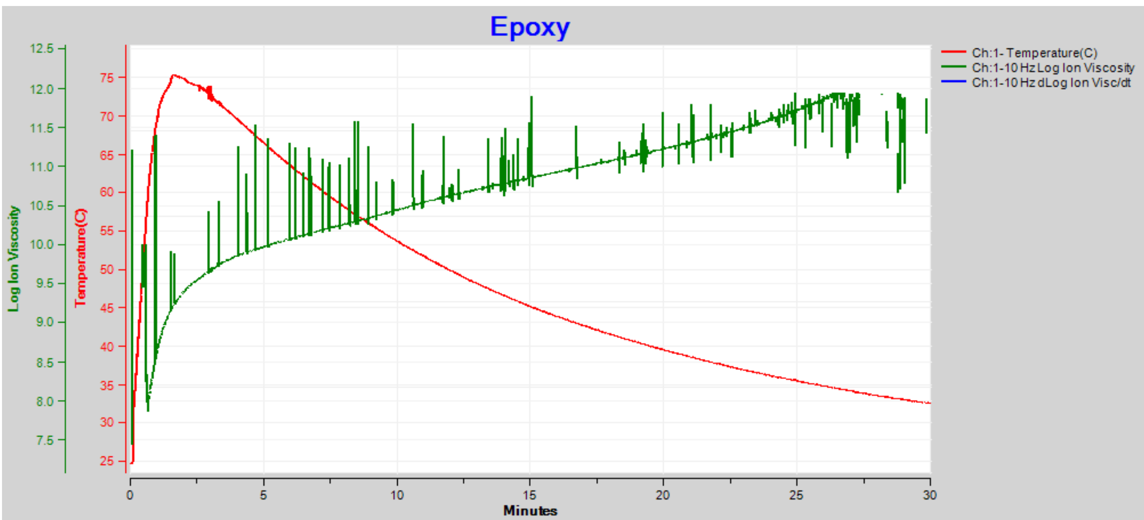

Figure 36-2
Epoxy cure using parameters of Table 1

The *log(IV)* curve shows considerable noise in the form of spikes picked up from the local electrical environment. Although the overall behavior of *log(IV)* is apparent, these spikes will cause problems in detecting Critical Points of this cure and will introduce considerable noise in the calculation of *slope*.

Eliminating spikes with the median filter

A median filter acts as a spike cutter and can be very useful in eliminating or reducing this type of noise. In CureView the default value of the median filter parameter is 1, which disables the filter, resulting in the plot of Figure 36-2.

Increasing the value of this parameter increases the filtering action. Its effectiveness depends on the data acquisition rate relative to the run time and the distribution, width and height of the spikes. Consequently, the desired value must be determined by trial and error.

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Figure 36-3 shows *log(IV)* of the epoxy cure with a median filter parameter of 21. Because the data acquisition rate was very high compared to the time scale of the test—100 milliseconds per data point compared to a run time of 30 minutes—a large median filter value is necessary for good spike reduction.

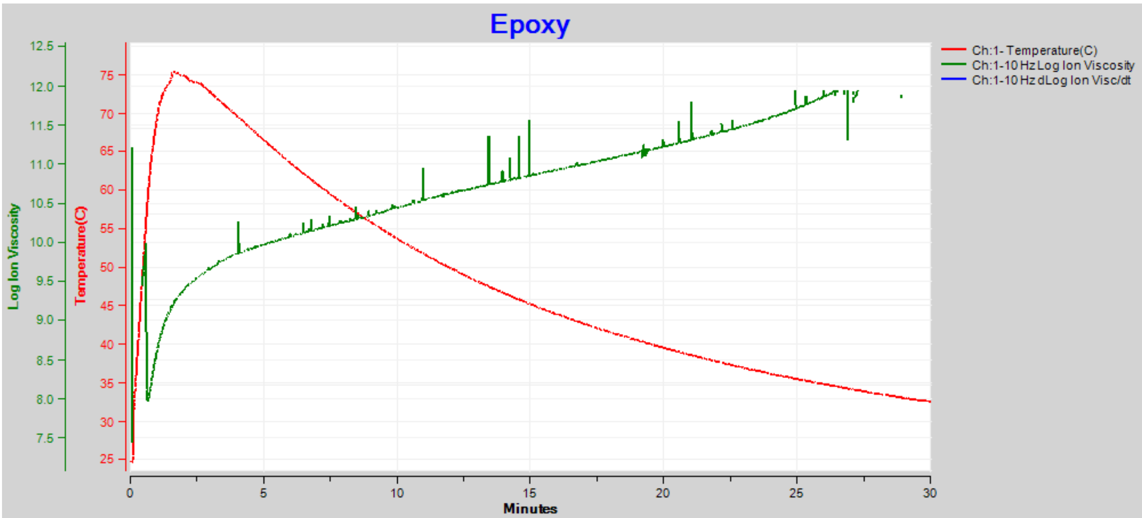

Figure 36-3
Epoxy cure using parameters of Table 1 and median filter value = 21

The number and height of the noise spikes has been considerably reduced but not completely eliminated. Further increasing the median filter parameter to 41 almost entirely removes the spikes, as shown in Figure 36-4.

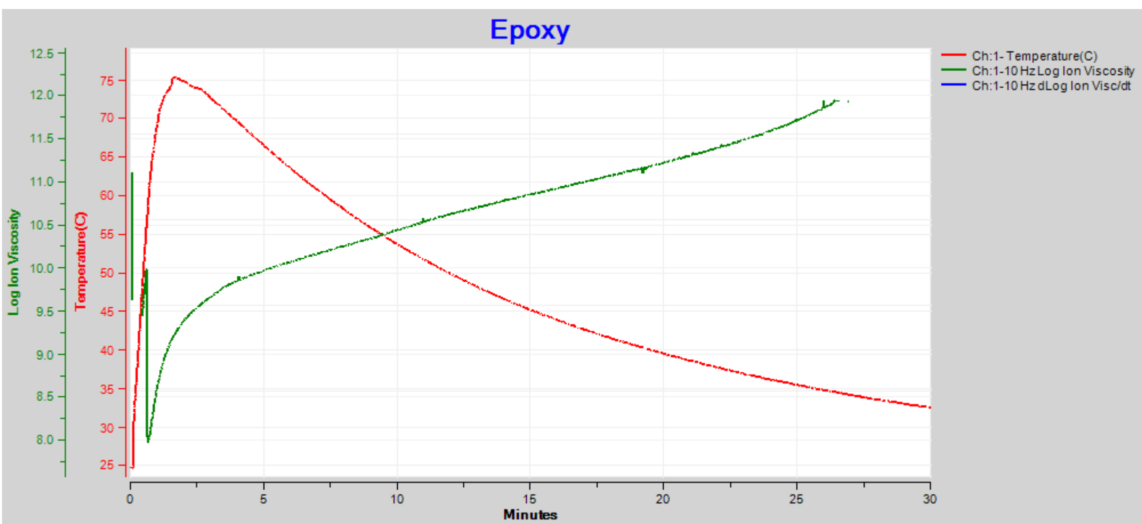

Figure 36-4
Epoxy cure using parameters of Table 1 and median filter value = 41

Figure 36-5 shows this *log(IV)* plot with the accompanying *slope* data, using the slope span of 8 listed in Table 36-1. Even though the *log(IV)* curve

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appears smooth, it actually has a small amount of noise, which is magnified in the process of calculating *slope*.

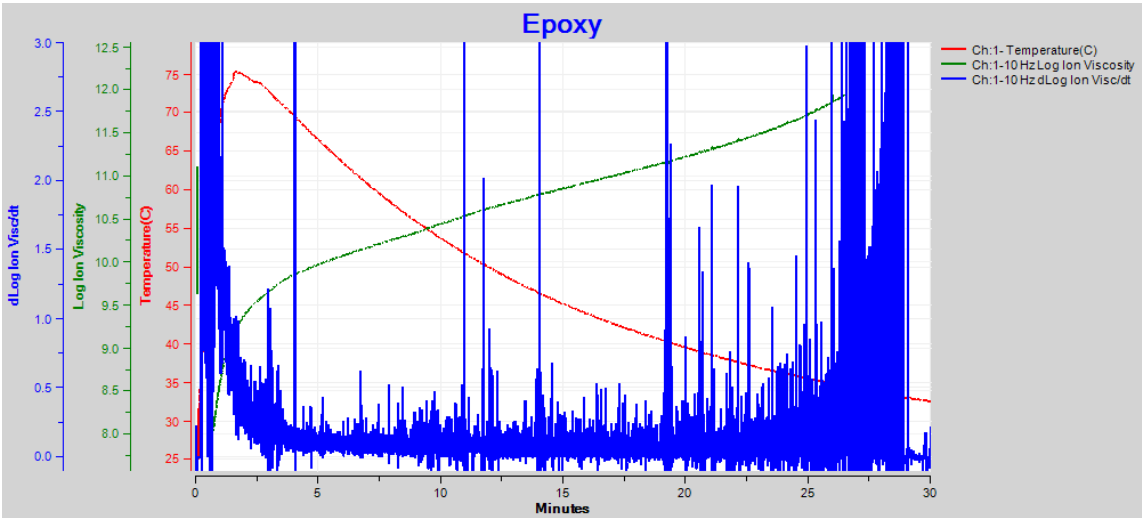

Figure 36-5
***Log(IV)* and *slope* of epoxy cure (Median filter increased to 41)**

Reducing noise by increasing *Sample Size*

Figure 36-6 shows typical raw *log(IV)* data with noise and illustrates how CureView uses a moving boxcar, or *rolling*, average.

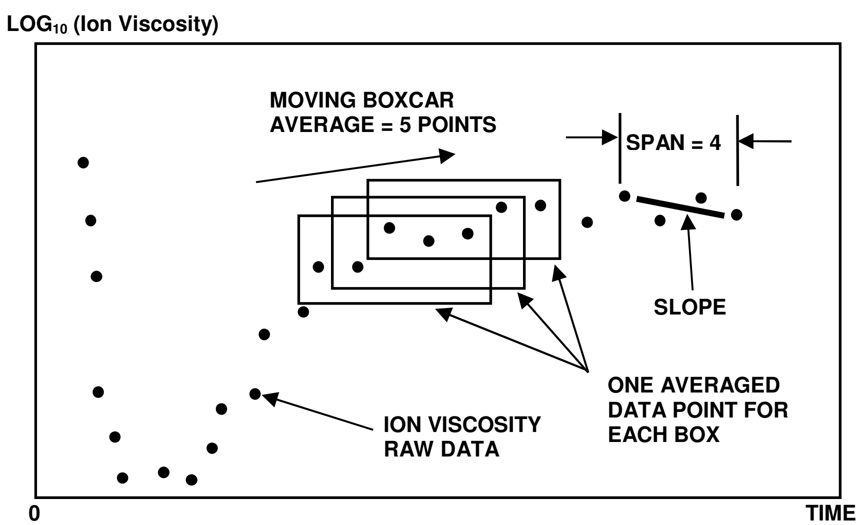

Figure 36-6
Signal processing: Sample Size and Slope Span

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In this picture a **Sample Size** of five raw data points is averaged together to obtain each new resultant point for *log(IV)*. Figure 6 also shows how **Slope Span** determines the calculation of *slope*.

Increasing **Sample Size** produces smoother processed data but the result responds more slowly to change. The averaged data point is considered to occur at the time halfway between the first and last data points used in the "boxcar."

While Figure 36-6 shows averaging of *log(IV)*, CureView actually averages the raw gain-phase-temperature data that are measured and later used to calculate *log(IV)*. Note that CureView does not average *slope* obtained from the *log(IV)* curve—*slope* noise is smoothed by setting the **Slope Span** parameter, which is discussed in the next section.

Figure 36-7 shows the epoxy cure when processed with the parameters of Table 36-2. Compared to Figure 36-5 the only change is the increase of **Sample Size** to 40 from 1.

Table 36-2
Noise reduction parameters for Figure 36-7

Median filter	41	Optimal median filter value
Sample size	40	Average using 40 data points
Slope span	8	Typical initial value for calculating slope
Data filter coefficient	0	"0" disables filtering of data
Slope filter coefficient	0	"0" disables filtering of *slope*

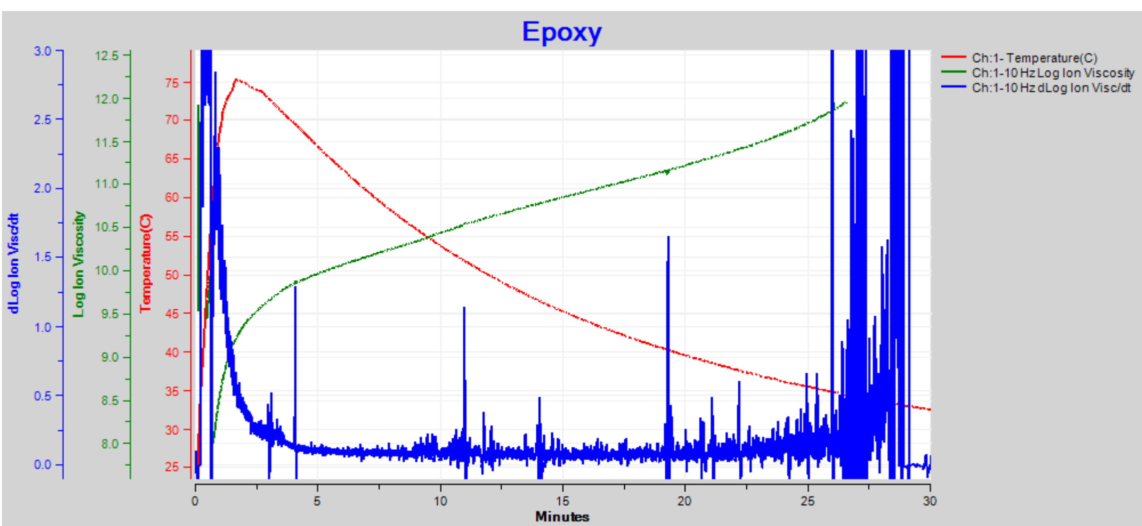

Figure 36-7
***Log(IV)* and *slope* using parameters of Table 2 (Sample Size increased to 40)**

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The *log(IV)* curve of Figure 36-7 appears almost identical to the curve of Figure 36-5, even with the large **Sample Size** of 41, because of the high density of data points. As a result, the smoothing of data occurs on time scales much less than the features in the curve. In this case, the major consequence of the larger **Sample Size** is the reduction of noise in *slope*.

Reducing noise in *slope* by increasing *Slope Span*

As shown in Figure 36-6, **Slope Span** is the number of *log(IV)* data points from end to end for the line segment that determines the calculation of *slope*. Larger values of **Slope Span** produce smoother *slope* data but the result responds more slowly to change. The data point for *slope* is considered to occur at the time in the center of the span.

Figure 36-8 shows the noise reduction in *slope* when processed with the parameters of Table 36-3. Compared to Figure 36-7, the only change is the increase of **Slope Span** to 80 from 8.

Table 36-3
Noise reduction parameters for Figure 36-8

Median filter	41	Optimal median filter value
Sample size	40	Average using 40 data points
Slope span	80	Increased to 80 from 8
Data filter coefficient	0	"0" disables filtering of data
Slope filter coefficient	0	"0" disables filtering of *slope*

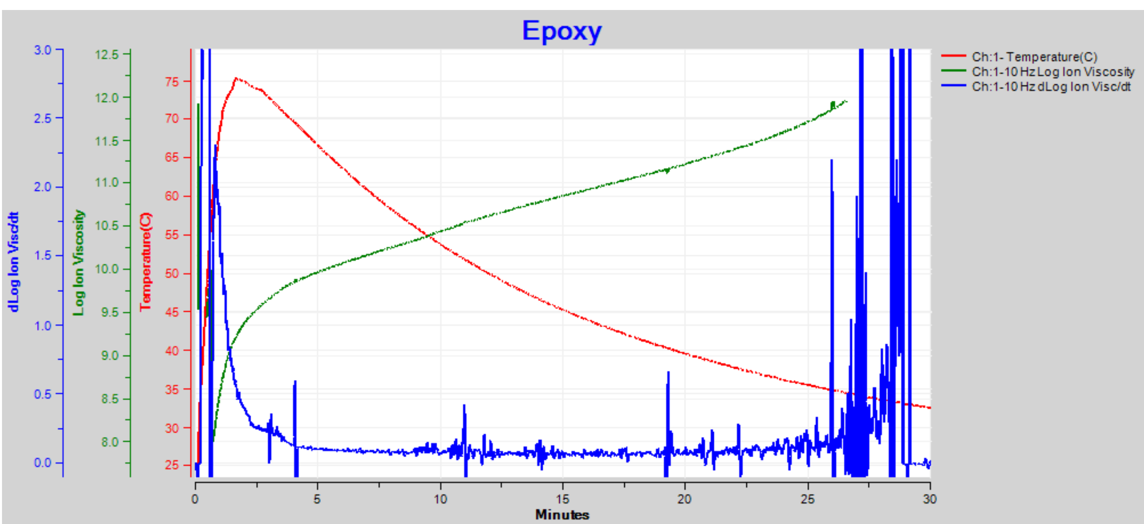

Figure 36-8
***Log(IV)* and *slope* using parameters of Table 3 (Slope Span increased to 80)**

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Reducing noise by increasing *Data Filter Coefficient*

Filtering of data using the **Data Filter Coefficient** is different from averaging of data using **Sample Size**. Filtering implements a numerical low pass filter, which is better for reducing high frequency noise while averaging is better for random noise. The differences are often subtle and the choice of how to use either filtering or averaging is largely a matter of user preference.

As with averaging, filtering smooths the raw gain-phase-temperature data, which in turn reduces noise in both *log(IV)* and *slope*. Larger values of **Data Filter Coefficient** produce smoother data but the result responds more slowly to change.

Figure 36-9 shows the noise reduction in both *log(IV)* and *slope* when processed with the parameters of Table 36-4. Compared to Figure 36-8, the only change is the increase of **Data Filter Coefficient** to 20 from 0.

Table 36-4
Noise reduction parameters for Figure 36-9

Median filter	41	Optimal median filter value
Sample size	40	Average using 40 data points
Slope span	80	Calculate slope using span of 80
Data filter coefficient	20	Increased to 20 from 0
Slope filter coefficient	0	"0" disables filtering of *slope*

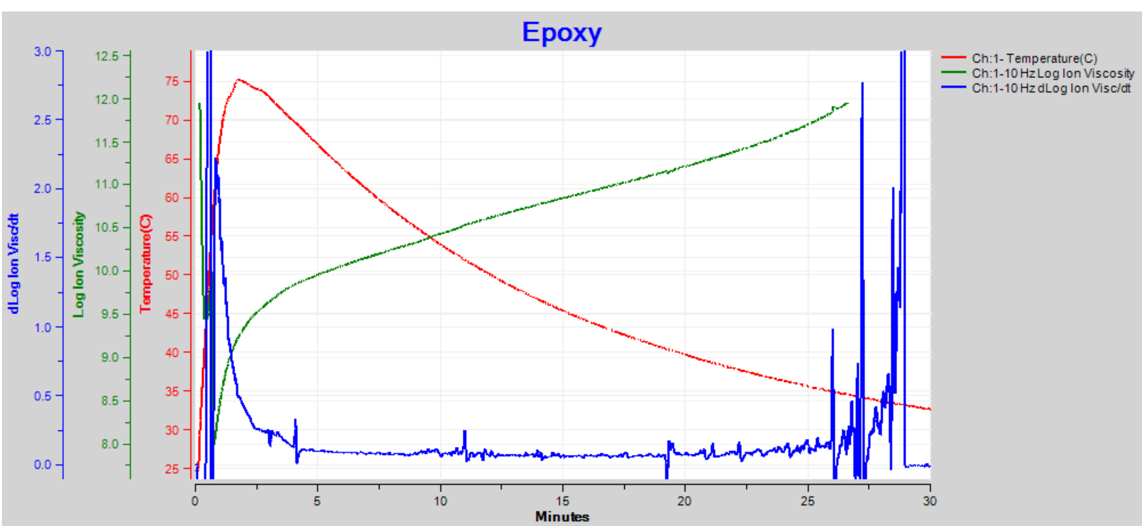

Figure 36-9
***Log(IV)* and *slope* using parameters of Table 4**
(Data Filter Coefficient increased to 20)

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Reducing noise by increasing *Slope Filter Coefficient*

Filtering of *slope* using the **Slope Filter Coefficient** implements a numerical low pass filter for processing of only slope data. Larger values of **Slope Filter Coefficient** produce smoother data but the result responds more slowly to change.

Figure 36-10 shows the noise reduction in *slope* when processed with the parameters of Table 36-5. Compared to Figure 36-9, the only change is the increase of **Slope Filter Coefficient** to 20 from 0.

Table 36-5
Noise reduction parameters for Figure 36-10

Median filter	41	Optimal median filter value
Sample size	40	Average using 40 data points
Slope span	80	Calculate slope using span of 80
Data filter coefficient	20	Filter with value of 20
Slope filter coefficient	20	Increased to 20 from 0

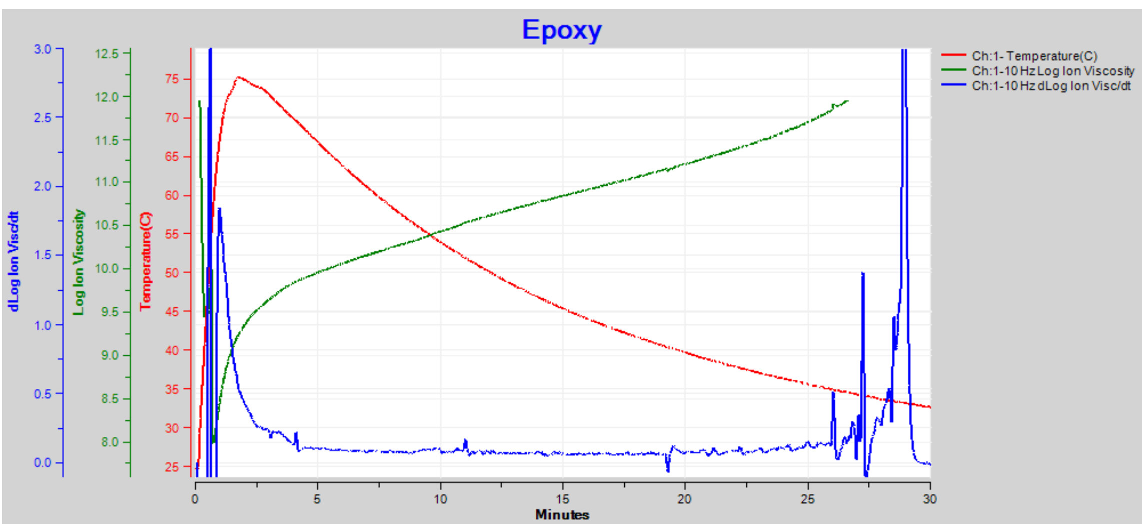

Figure 36-10
***Log(IV)* and *slope* using parameters of Table 5**
(Slope Filter Coefficient increased to 20)

Time of *log(IV)* and *slope* data points

The Filter/Average window of Figure 36-11 shows the option to **Average and Filter Time**. Enabling this feature causes CureView to adjust the time assigned to *log(IV)* and *slope* data, resulting in better correspondence between

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the calculated *log(IV)* and its actual physical behavior. Enabling **Average and Filter Time** also improves the alignment between *log(IV)* and *slope*, and is the preferred option.

If **Average and Filter Time** is not enabled, then the time assigned to processed *log(IV)* is simply the time stamp of the raw data point. The time assigned to *slope* is the time stamp of the first point of the span.

Conclusion

***TIP*—Use fast measurement speeds to generate more data points for better noise reduction**

- The resulting larger data files and longer processing times should be balanced against improved noise rejection
- More data points in a file allow better smoothing of noise while reducing distortion in the overall curve
- A larger **Sample Size, Slope Span, Data Filter Coefficient or Slope Filter Coefficient** produces more smoothing of noise but potentially more distortion of data

***TIP*—Delay start of averaging or filtering when *log(IV)* changes rapidly during early cure, to avoid distortion of *log(IV)* data**

- *Log(IV)* may change rapidly because the material under test suddenly contacts the sensor or heats quickly
- See Figure 36-11 for input windows to delay start of averaging or filtering

***TIP*—Delay start of slope filtering until after Critical Point 3 (CP(3)) to avoid distortion of slope data**

- CP(3) is the point of maximum slope, indicating the maximum reaction rate (see application note AN2.35, "Case Study 1—Data Processing to Reduce Noise")
- Slope changes most rapidly around CP(3) and filtering slope before this point would affect its time of occurrence and reduce its peak value
- See Figure 36-11 for input window to delay start of slope filtering

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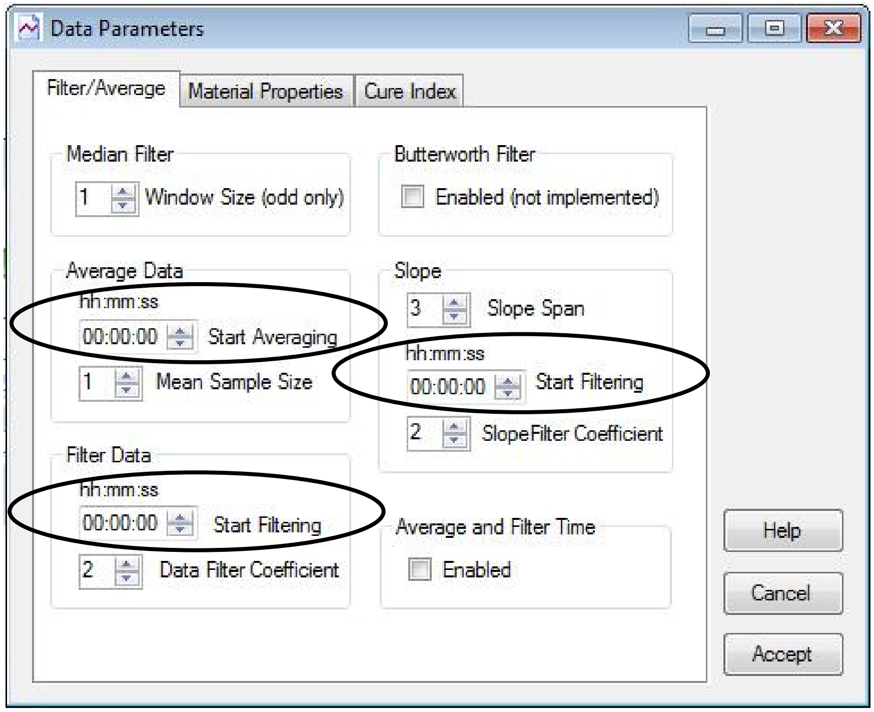

Figure 36-11
Filtering and averaging parameter window, showing
Input windows for delaying the start of averaging and filtering

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