



Anton Paar

Measure,
what is measurable,
and make measurable
that which is not.

Galileo Galilei (1564-1642)

Instruction Manual

Rheoplus Software

Volume 3 - Analysis

Software Version: 2.6x



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1 Introduction

This manual describes the data analysis and evaluation methods in the Rheoplus Software. For each method you will find a description of the method and its parameters. Further, this manual includes a section with general information about setting up the analysis window.

Should you require further information, you are welcome to contact our local distributor or Anton Paar Germany directly.

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Anton Paar Germany GmbH



2 Safety Instructions

Make sure you read and understand all the safety instructions given in this section and throughout the manuals before installing and operating the equipment. Follow the instructions in this manual at all times.

The manual contains important advice and warnings. Read them carefully and follow all instructions to avoid danger to yourself and others and / or damage to the equipment.

General Information

- The Rheoplus software by Anton Paar Germany GmbH has been developed for controlling Anton Paar and Physica rheometers and viscometers. It is used for the recording, evaluation and presentation of measurement data.
- All measurement data obtained with this equipment should be checked for plausibility before consequential actions are taken based on this data.
- Before using the software read all safety instructions and information regarding the use of the equipment. Follow the instructions at all times.
- Anton Paar Germany GmbH and its suppliers shall not be liable for any damages whatsoever (including, without limitation, damages for loss of business profits, business interruption, loss of business information, or other pecuniary loss) arising from the use or inability to use this product, even if Anton Paar Germany GmbH has been advised of the possibility of such damages. In any case, Anton Paar Germany GmbH's liability shall be limited to the amount actually paid by you for this product. This limitation does not apply to damages which were caused by Anton Paar Germany GmbH with intent or due to gross negligence. Likewise, claims which are based on mandatory legal rules regarding product liability remain unaffected.



3 Symbols

The following symbols will be used in this manual:

**Warning:**

A section marked with this sign contains important information. Read the section carefully and follow all instructions. Disregarding the information may lead to injuries and / or damage to the equipment.

**Important:**

A section marked with this symbol contains important information on how to handle the equipment and ensure the reliability of the measurement results. Disregarding this information may cause damage to the equipment.

**Hint:**

A section marked with this symbol contains additional information.



4 Setting up the Analysis Window

This section contains some general information about how to create and set up an analysis. You learn how to select a method and where you can set the parameters. Further, you will find information about the selection of the input data and the naming options for the evaluation results.

In the analysis window, you select the methods for the evaluation of your measurement data. The data can be evaluated by several methods in a row, e.g. smoothing the data first, then evaluating them using a rheological model.

The analysis window uses a table format where the steps of the analysis are the rows and the different data settings and parameters are the columns. The cells can be edited by double-clicking or with the respective command on the analysis menu.

The analysis menu is available in the workbook when an analysis window is the active window.

4.1 'Analysis | Analysis step'

The 'Insert' command adds a new step before the currently selected. This command has the same function as the 'Insert' button in the analysis window.

The 'Append' command adds a new step after the currently selected step. This command has the same function as the 'Append' button in the analysis window.

The 'Delete' command deletes the currently selected step. This command has the same function as the 'Delete' button in the analysis window.

4.2 'Analysis | Options'

The settings in the options dialog decide how much data are shown in the result window and whether all defined steps are applied to the input data.

- Long Method Information
shows detailed information about the selected method in the result window
- Show Method Name
shows the name of the selected method in the result window

- **Show Data Information**
displays the location and file name of the datapool as well as the names of the input and output data series in the result window
- **Clear Result Window before Start / Clear Result Window before Start autom. measuring**
erases the information from a previous analysis in the result window. It is recommended to use this option to avoid a data overflow.
- **Which Analysis Steps Should Be Calculated?**
Select the first option to run all defined analysis steps. If you select the second option, enter the range of analysis steps that you want to be carried out. This way you can run a different analysis without having to change the complete method.

4.3 'Analysis I Method'

This command displays a dialog where you can select an analysis method from the list of available (i.e. installed) methods. Highlight the method you would like to use and click 'OK'. This dialog can also be opened by double-clicking on a cell in the 'Method' column.

If two or more methods are defined in the analysis window you will need to select the method you want to change in a dialog that is opened with this command.

4.4 'Analysis I Parameters'

In the parameter dialog, which also can be accessed by double-clicking on a cell in the 'Parameters' column, you choose the variables for the selected analysis method. The parameters and settings are specific for each method and are described later in this manual.

The 'Default' button resets the settings for the input variables and for the parameters to the standard values. The 'Info' button opens a text window that contains information about the selected evaluation method.

4.5 'Analysis I Input Data'

In the input data dialog box, you select the data series or data series intervals to which you would like to apply the selected analysis methods. To add a data series, highlight it in the list of 'Possible Data Series' and click the right arrow button.

Highlight the data series and add it with the arrow button or a double-click

Select 'Complete...' to analyse the whole data series or 'Regions...' to define the parts for analysis

Enter interval and point number(s) or just the interval number(s). Then click 'Append'.

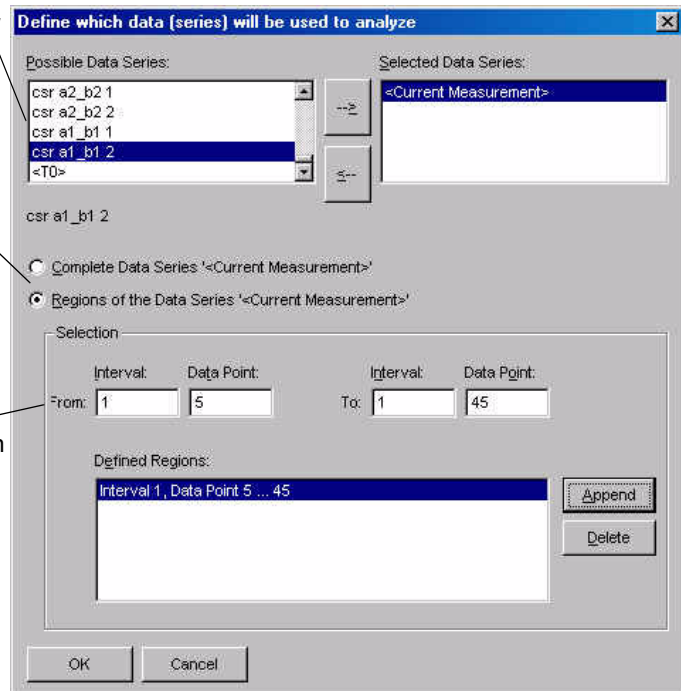


Fig. 4 - 1 Selection of input data

If only parts of the data series are to be evaluated you enter the interval number (from the measuring profile or table) and the point number (see table). Then click 'Append' to add your selection to the list of defined regions.

To remove a selected data series you highlight it in the list of selected data series and click the left arrow button.

If two or more methods are defined in the analysis window you will need to select the method you want to change in a dialog that is opened with this command.

Besides the data series (both measurement and analysis results) temporary data series can be used as input. The temporary data series are marked <T0>, <T1> and so on. They can be generated by an analysis method if the option 'Temporary Result' has been activated in the output data dialog box.

4.6 'Analysis I Output Data'

The analysis result is usually added to the datapool as a new data series. In the output data dialog you can -similar to the generation of data series names in a measurement- define a name for the data series or use macros to automatically create a name for the result data series.

To use a macro, select it from the list and click 'Insert'. It is possible to link a number of macros.

Available Macros:

Act. Date (YYMMDD)	Current date with year, month and date
Act. Time (HHMM)	Current time with hour and minutes
Number from Job List with x Decimal Places	Step number (see job list)
Analysis Method of the 1st / Actual Analysis Step	Name of the method for the first step or name of the method in the step where the output data are edited
Field 'xxx' of the 1st Input Data Series	Information in the respective field of the input data series of the first analysis step
Name of Datapool	name of the datapool in which the data series is stored
Datapool File Extension	File extension of the datapool in which the data series is stored*
Input Data Series of 1st / Actual Analysis Step	Name of the input data series of the first or current analysis step
Login User Name	Name of the currently logged in user (only if Login is used)
Constant Setting Temperature	Set temperature from the measurement profile

If you are using several steps in an analysis and are only interested in the final result of the last step it is recommended that you select 'Temporary Result' for all analysis steps but the last. For each step you can define the temporary data series <Tn> (where n is a number) of the previous step as the input data. This way the input data are current each time the analysis is carried out. If you further uncheck the option 'Data Series in Datapool' the temporary results will not be stored in the datapool.

4.7 'Analysis I LIM'

The command 'LIM' is only available if the Rheoplus software runs in LIMS mode (see the LIM/SAP manual for more information on linking to LIM/SAP master systems). It opens a dialog where you can select additional keys that pass analysis results to the master system. Select the required values from the list and enter the necessary settings.

The dialog can also be opened by double-clicking the 'LIM data' column in an analysis window (only in LIMS mode).

4.8 'Analysis I Start / Stop'

The start command starts the analysis; all selected steps will be carried out and the results will be presented in the result window during the calculation. Please observe that some methods may have long calculation times.

The stop command interrupts the analysis that is currently running, a result data series is not created. If the analysis contains several steps, the result data series from the steps before the stop are stored in the datapool. It has the same function as the stop button.

4.9 'Analysis I Clear Results'

The 'Clear Results' command erases the information currently displayed in the result window; it does not delete the data series. The 'Clear' button in the analysis window has the same function.

5 Rheology Standard 1, 2 and 3

The method groups <Rheology Standard 1>, <Rheology Standard 2> and <Rheology Standard 3> are installed by default. They include mathematical methods and smoothing as well as a number of rheological models.

The methods in this group replace those methods with identical names in previous versions (< 2.10) of the US200 software. In case you wish to use the older methods these can be found in the group <Rheology old>. The difference between the older and the current methods is that the new methods allow to select the variables to which you want to apply the evaluation. The methods that include the selection of variables are marked with 'I'; as a default setting the variables are selected that the method is commonly used for.

The evaluation methods of the group <Rheology Standard 1> are regression methods. They have some parameter settings in common; these will be described here.

Given Regression Parameters

The equation that describes the evaluation methods contains variables, that are selected by the user, and regression parameters, that are calculated by the evaluation algorithm. If any of these regression parameters is known, you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters. The regression parameters are the output data of the evaluation.

Show Parameter Settings (only available for some methods)

If this option is checked the result field in the analysis window will include the selections that have been made for the parameter setup. If checked for the example in 5.1, the result field would display that 'Shear rate' has been selected as x-variable and 'Shear stress' as y-variable, that all three regression parameters are wanted and that 'Relative' error has been selected as the weighting method.

Show Result Table (only available for some methods)

If this option is checked the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

Output Range (only available for some methods)

The 'Output Range' dialog box allows to interpolate the values of the output data series instead of using the range of data points available in the input data series. An extrapolation is also possible. To use the output range, select the option 'User defined' and enter the x-values for which you want to calculate the data points. There are three options available; a description of the interpolation methods can be found in the chapter 'Interpolation Single Point' (chapter 6.4).

5.1 2nd Log. Polynomial I

This analysis fits a logarithmic polynomial of the second order to the measurement data. It can be used for all types of measurement, as a default it is used to calculate the viscosity as a function of the shear rate in rotational measurements.

Several rheological models -also included as analysis methods- are special cases of the 2nd order logarithmic polynomial. Therefore, this method can be used to evaluate the fitting of different methods by selecting one or more of the regression parameters accordingly.

- Newton (with $b=1$ and $c=0$)
- Ostwald (with $c=0$)

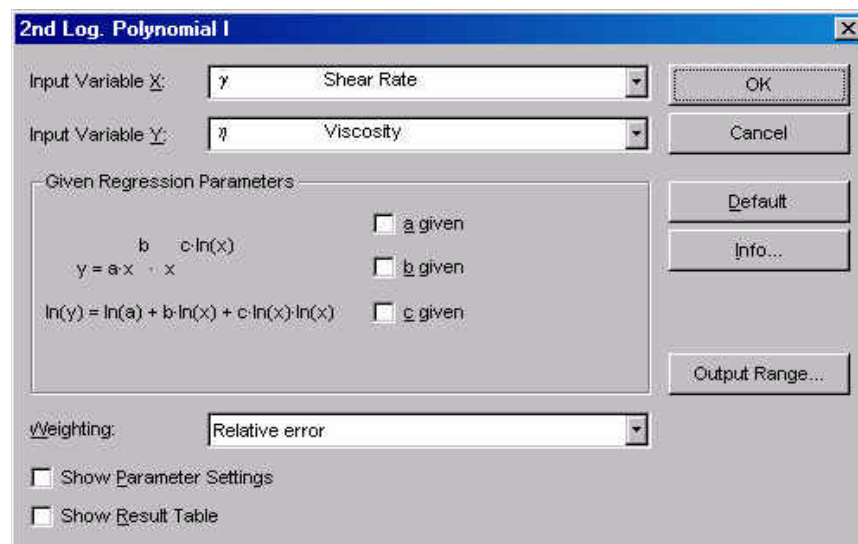


Fig. 5 - 1 2nd Log. Polynomial I - Parameter settings

$$y = a \cdot x^b \cdot x^{c \cdot \ln(x)}$$

or

$$\ln(y) = \ln(a) + b \cdot \ln(x) + c \cdot \ln(x) \cdot \ln(x)$$

x - input variable x

y - input variable y

a - coefficient

b - first exponent

c - second exponent

5.1.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable).

Regression Parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is the relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings'

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup. If checked for the example in Fig. 5 - 2 the result field would display that 'Shear rate' has been selected as x-variable and 'Viscosity' as y-variable, that all three regression parameters are wanted and that 'Relative' error has been selected as the weighting method.

Show Result Table'

If the option 'Show Result Table' is checked the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.1.2 Example

The example in the figure below shows the fitting of a 2nd Logarithmic Polynomial to the flow curve of a high viscous oil with a zero shear viscosity. The selected method can be used to describe the shear-thinning region, though it cannot cover the whole curve.

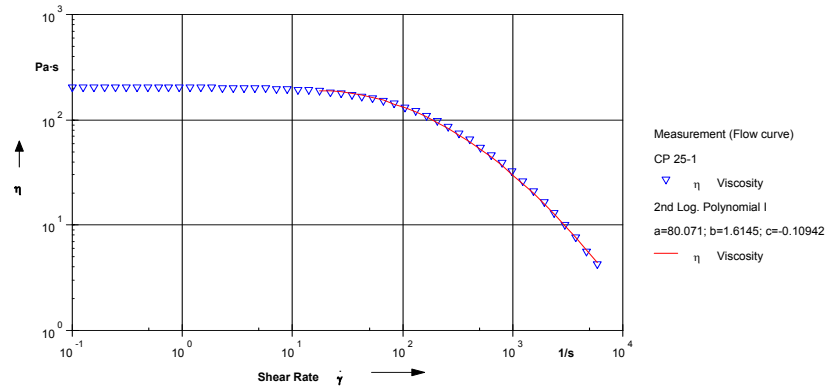


Fig. 5 - 2 2nd Log. Polynomial - Example

5.2 2nd Polynomial I

This analysis fits a polynomial of the second order to the measurement data. It can be used for all types of measurement, as a default it is used to calculate the shear stress as a function of the shear rate in rotational measurements, i.e. an evaluation of the flow curve.

Several rheological models -also included as analysis methods- are special cases of the 2nd order polynomial. Therefore, this method can be used to evaluate the fitting of different methods by selecting one or more of the regression parameters accordingly.

- Newton (with $a=0$ and $c=0$)
- Bingham (with $c=0$)

It is also similar to the Herschel-Bulkley model (with $b=0$; if the regression parameter p of the Herschel-Bulkley model is equal to 2).

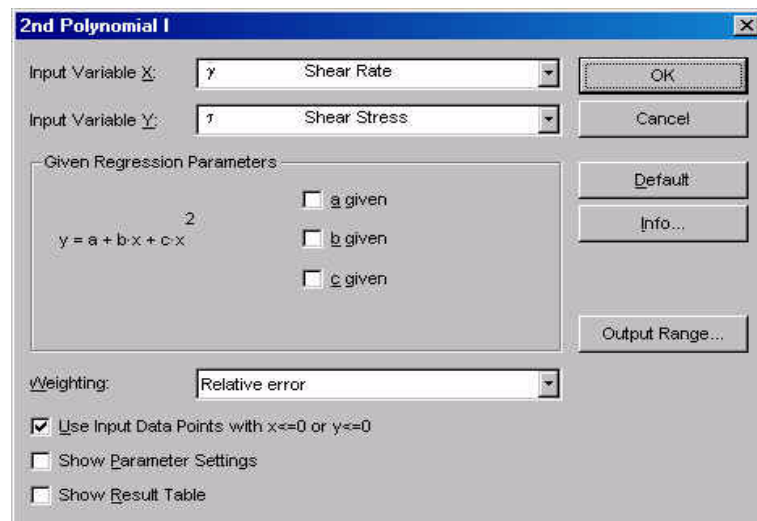


Fig. 5 - 3 2nd Polynomial I - Parameter settings

$$y = a + b \cdot x + c \cdot x^2$$

- x - input variable x
- y - input variable y
- a - coefficient of the 0th order
- b - coefficient of the 1st order
- c - coefficient of the 2nd order

5.2.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable).

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is the relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup. If checked for the example in Fig. 4?3 the result field would display that 'Shear rate' has been selected as x-variable and 'Viscosity' as y-variable, that regression parameter 'a' is known while that the other two are wanted and that 'Relative' error has been selected as the weighting method.

Show Result Table

If the option 'Show Result Table' is checked the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.2.2 Example

The example in the figure below shows the fitting of a 2nd Polynomial to the flow curve of a high viscous oil. The selected method can be used for the first region of the flow curve up to the onset of shear thinning behaviour.

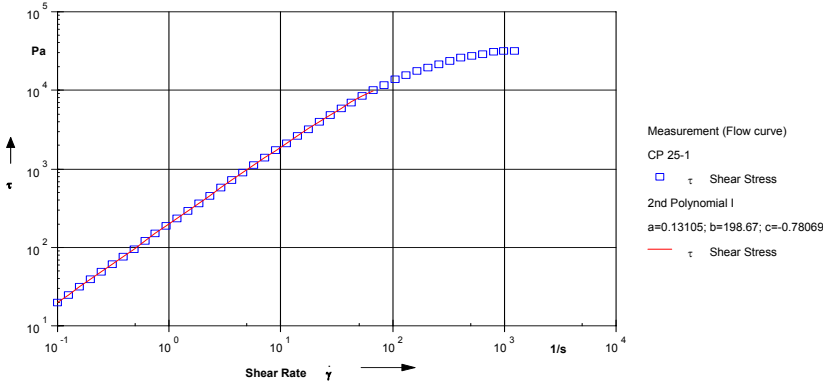


Fig. 5 - 4 2nd Polynomial - Example

5.3 3rd Polynomial I

This analysis fits a polynomial of the third order to the measurement data. It can be used for all types of measurement, as a default it is used to calculate the shear stress as a function of the shear rate in rotational measurements, i.e. an evaluation of the flow curve.

Several rheological models -also included as analysis methods- are special cases of the 3rd order polynomial. Therefore, this method can be used to evaluate the fitting of different methods by selecting one or more of the regression parameters accordingly.

- Newton (with $a=0$, $c=0$ and $d=0$)
- Bingham (with $c=0$ and $d=0$)
- Steiger-Ory (with $a=0$ and $c=0$)

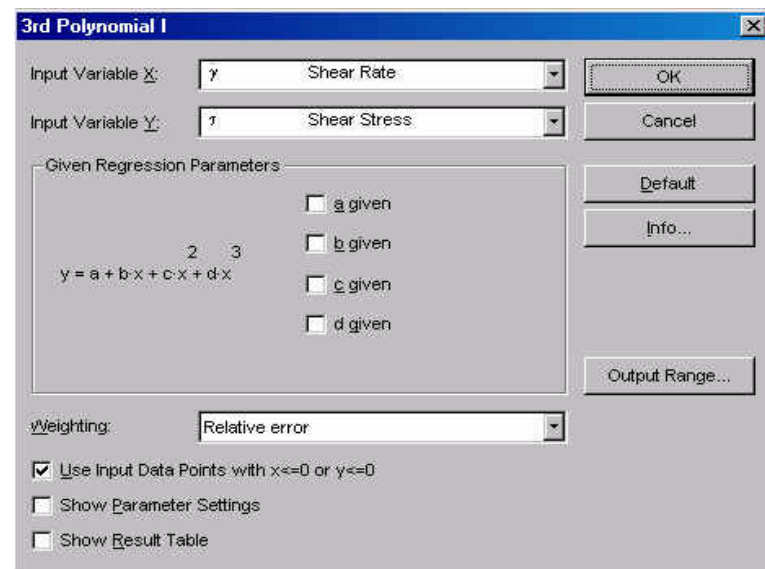


Fig. 5 - 5 3rd Polynomial I - Parameter settings

$$y = a + b \cdot x + c \cdot x^2 + d \cdot x^3$$

x - input variable x

y - input variable y

a - coefficient of the 0th order

b - coefficient of the 1st order

c - coefficient of the 2nd order

d - coefficient of the 3rd order

5.3.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable).

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is the relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup. If checked for the example in Fig. 4?3 the result field would display that 'Shear rate' has been selected as x-variable and 'Viscosity' as y-variable, that regression parameter 'a' is known while that the other two are wanted and that 'Relative' error has been selected as the weighting method.

Show Result Table

If the option 'Show Result Table' is checked the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.3.2 Example

The example in the figure below shows the fitting of a 3rd Polynomial to the flow curve of a high viscous oil. The selected method can be used for the first region of the flow curve up to the onset of shear thinning behaviour.

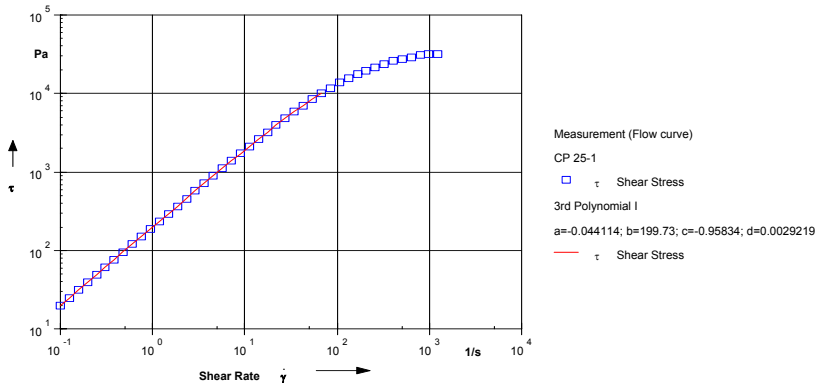


Fig. 5 - 6 3rd Polynomial - Example

5.4 4th Log. Polynomial I

This analysis fits a logarithmic polynomial of the fourth order to the measurement data. It can be used for all types of measurement, as a default it is used to calculate the viscosity as a function of the shear rate in rotational measurements.

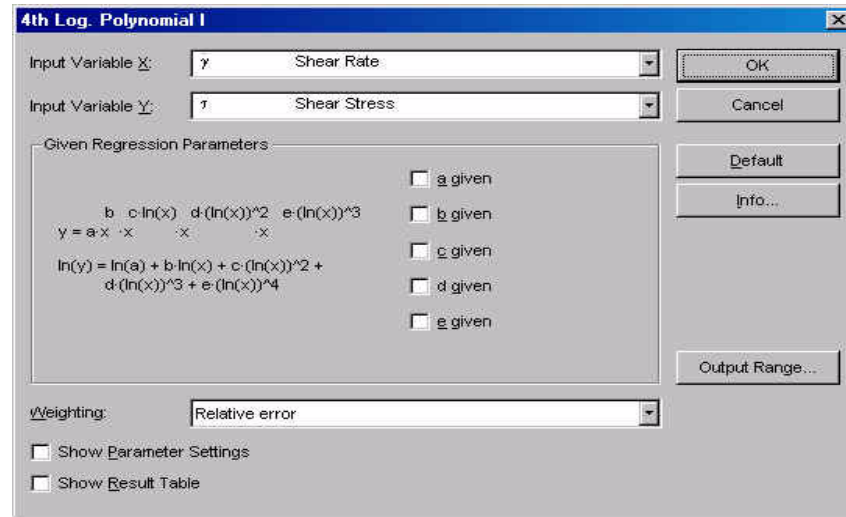


Fig. 5 - 7 4th Log. Polynomial I - Parameter settings

$$y = a \cdot x^b \cdot x^c \cdot \ln(x) \cdot x^d \cdot (\ln(x))^2 \cdot x^e \cdot (\ln(x))^3$$

or

$$\ln(y) = \ln(a) + b \cdot \ln(x) + c \cdot (\ln(x))^2 + d \cdot (\ln(x))^3 + e \cdot (\ln(x))^4$$

x - input variable x
y - input variable y
a - coefficient
b - 1st exponent
c - 2nd exponent
d - 3rd exponent
e - 4th exponent

5.4.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable).

Regression Parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is the relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup. If checked for the example in Fig. 4?2 the result field would display that 'Shear rate' has been selected as x-variable and 'Viscosity' as y-variable, that all three regression parameters are wanted and that 'Relative' error has been selected as the weighting method.

Show Result Table

If the option 'Show Result Table' is checked the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.4.2 Example

The example in the figure below shows the fitting of a 4th Logarithmic Polynomial to the flow curve of paste with a zero shear viscosity. The selected method can be used to describe the plateau and the shear thinning region.

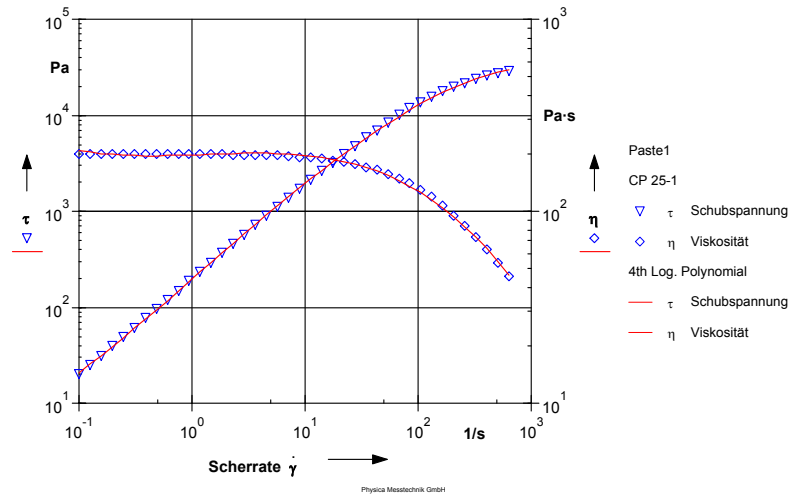


Fig. 5 - 8 4th Log Polynomial I - Example

5.5 4th Polynomial I

This analysis fits a polynomial of the fourth order to the measurement data. It can be used for all types of measurement, as a default it is used to calculate the shear stress as a function of the shear rate in rotational measurements, i.e. an evaluation of the flow curve.

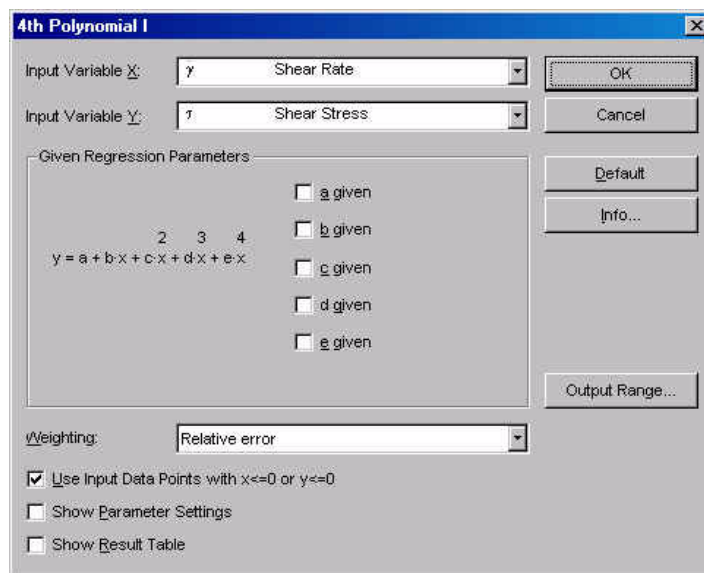


Fig. 5 - 9 2nd Polynomial I - Parameter settings

$$y = a + b \cdot x + c \cdot x^2 + d \cdot x^3 + e \cdot x^4$$

x - input variable x
y - input variable y
a - coefficient of the 0th order
b - coefficient of the 1st order
c - coefficient of the 2nd order
d - coefficient of the 3rd order
e - coefficient of the 4th order

5.5.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable).

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is the relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.5.2 Example

The example in the figure below shows the fitting of a 4th Polynomial to the flow curve of material with a zero shear viscosity and shear thinning behaviour.

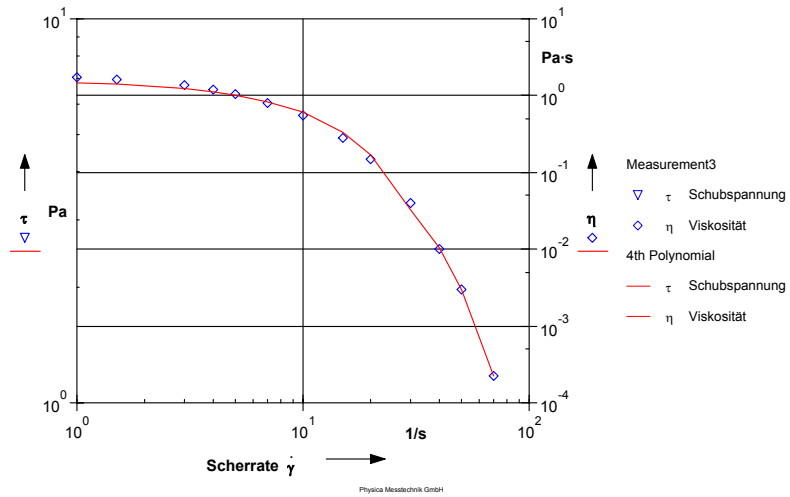


Fig. 5 - 10 4th Polynomial - Example

5.6 3 Interval Thixotropy Test

This evaluation method can be used to determine how far the structure of a material can be re-built after shear or how long time the recovery takes. To be able to do this the sample is measured with a three-interval test: rest-shear-rest. The first and the third interval usually have identical measurement parameters.

The first interval is necessary to obtain a reference value for the sample properties at rest, during the second interval the material is sheared and during the third interval the recovery of the sample structure can be observed. A suitable measurement template can be found under the name '3 Interval Thixotropy Test' both in 'Standard Tests Oscillation' and 'Standard Tests Rotation'.

Fig. 5 - 11 3 Interval Thixotropy Test - Parameter Settings

5.6.1 Parameter settings

Test Types of the 3 Measuring Intervals

Select the test types according to the type of the input data. If the oscillation mode has been used for both the rest and the recovery interval, select the option 'Osci-xxx-Osci'; if all three intervals have been carried out in rotational mode select the option 'Rot-Rot-Rot'.

Interval Numbers of the 3 Measuring Intervals

Enter the numbers for the rest, load and recovery interval as they have been set in the measurement profile. A change of the standard settings is necessary e.g. if the measurement contains additional intervals before the rest interval. Intervals should not be added between the intervals of the 3 ITT test to avoid errors in the evaluation.

Steady State Check for Rest Interval

The value for 'Check Region at Interval End' gives the number of points in percent of the total number of points that is used for the steady state check at the end of the recovery interval. The steady state check is used to determine whether the sample properties are still changing or whether the structure re-built has reached the maximum level. If the value does not change more than the value set as 'Max. Allowed Deviation' the steady state is reached.

5.6.2 Calculation for Recovery Interval

Calculate Structure Recovery after

This method calculates the degree of recovery by comparing the viscosity or storage modulus after a selected time period with the value at the end of the rest interval. The structure recovery is given in percent.

Calculate γ -Difference

This method calculates the absolute difference between the values at the end of the load interval and the end of the recovery interval. For rotational tests the viscosity value is used, for oscillatory tests the storage modulus.

This option is only available if the same test type has been used for the load and the recovery interval.

Calculate Time for Structure Recovery

The value for the required structure recovery is entered in percent, and the evaluation method checks the time period necessary to reach this recovery level. The structure recovery is determined by comparing the values at the end of the rest interval and the end of the recovery interval.

Calculate Time until $G'=G''$

The values for G' and G'' in the recovery interval are checked and the time at which G' equals G'' is used as the analysis result. The time interval starts with the start of the recovery interval. The crossover point of G' and G'' is of interest because it determines the change from mainly viscous to mainly elastic behaviour.

5.6.3 Example

The example shows the storage and loss modulus for two paint samples. The samples have been measured in oscillatory mode during the rest and the recovery interval, for the load interval a shear rate similar to that in the application of the paint has been applied. For the application the point where G' equals G'' is of interest because levelling is not to be expected after that point; therefore the option 'Calculate Time until $G'=G''$ ' has been used. Sample 1 (triangles) reaches this point after about 31 s, whereas sample 2 (circles) requires about 53 s.

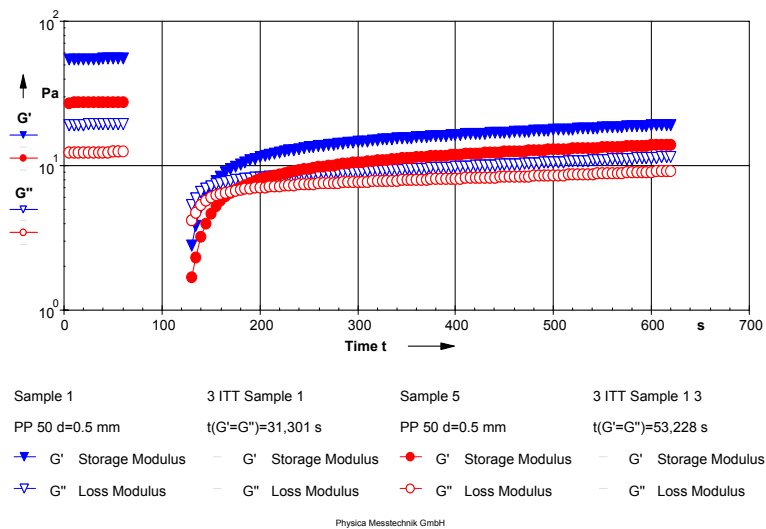


Fig. 5 - 12 3 Interval Thixotropy Test - Example

5.7 Arrhenius I

The Arrhenius equation describes the change of the viscosity with temperature. The equation is valid for liquid materials. It can also be used to describe the temperature dependency of the zero shear viscosity.

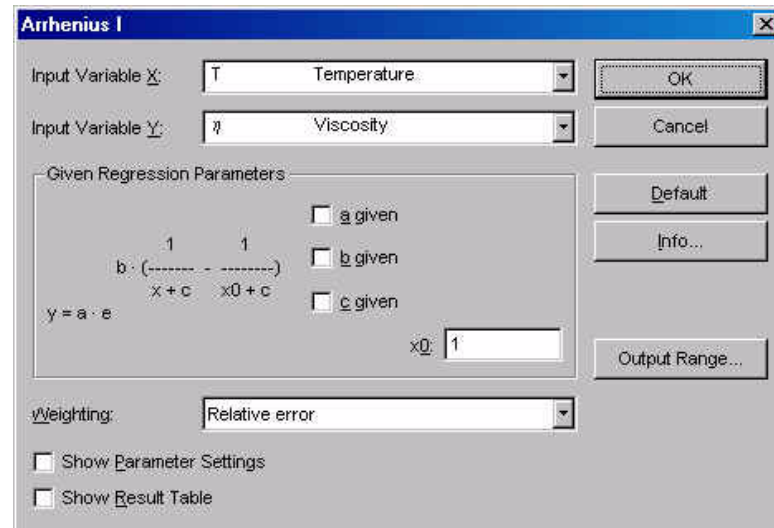


Fig. 5 - 13 Arrhenius I - Parameter settings

$$y = a \cdot e^{b \cdot \left(\frac{1}{x+c} - \frac{1}{x_0+c} \right)}$$

x - input variable x

y - input variable y

x0 - reference

a = y(x0)

$$b = \frac{E}{A} \quad (\text{with } R = 8.314 \text{ J/mol})$$

with: x + c > 0

x0 + c > 0

x > 0

x0 > 0

5.7.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable).

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is the relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup. If checked for the example in Fig. 4?3 the result field would display that 'Shear rate' has been selected as x-variable and 'Viscosity' as y-variable, that regression parameter 'a' is known while that the other two are wanted and that 'Relative' error has been selected as the weighting method.

Show Result Table

If the option 'Show Result Table' is checked the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.7.2 Example

The example below shows temperature dependence of the complex viscosity of a hotmelt measured in an oscillation temperature sweep and the Arrhenius fit.

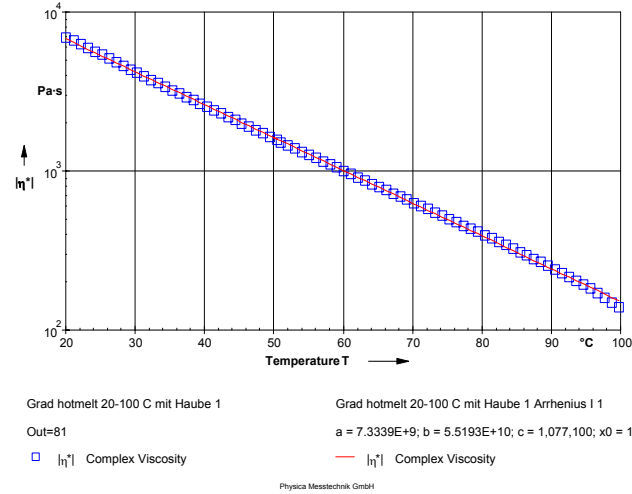


Fig. 5 - 14 Arrhenius - Example

5.8 Auto-Regression I

Auto-Regression can be used to try out a number of models on the measurement results. The software checks the fitting of the selected models and chooses the one with the best correlation ratio for the final evaluation.

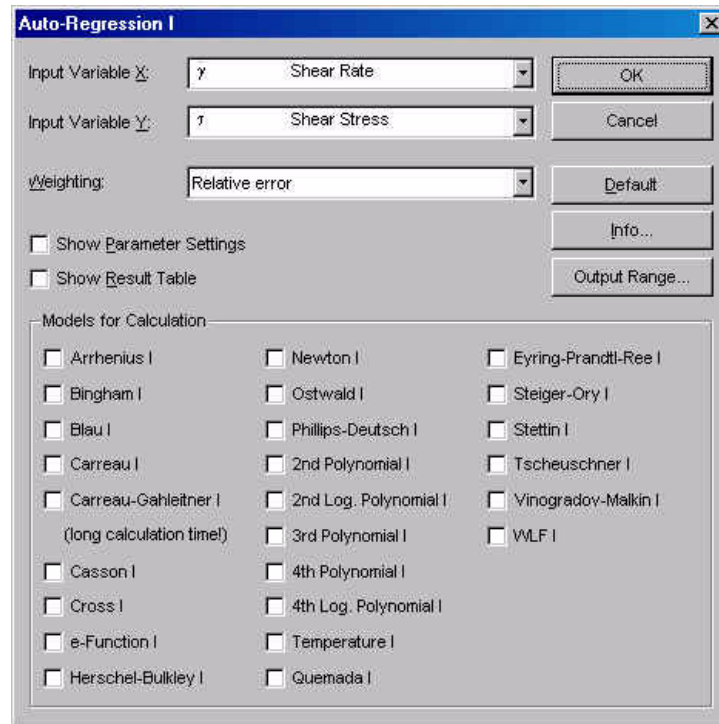


Fig. 5 - 15 Auto-Regression I - Parameter settings

As a result the name and equation of the best-fitting model are shown with the calculated regression parameters.

5.8.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable).

Weighting

The recommended setting for 'Weighting' is the relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

Models for Calculation

Select the models you want the software to check for. Please note that the more models you select, the longer the calculation time will be.

5.9 Bingham I

The Bingham equation describes the flow curve of a material with a yield stress and a constant viscosity (Newtonian behaviour) at stresses above the yield stress. It is frequently used for foodstuff or cosmetics. Related models are the Casson equation and the Herschel-Bulkley equation which also describe materials with a yield stress.

The parameter a is calculated as the y-axis value at $x=0$, the parameter b is calculated as the slope of the curve at $x \rightarrow \infty$.

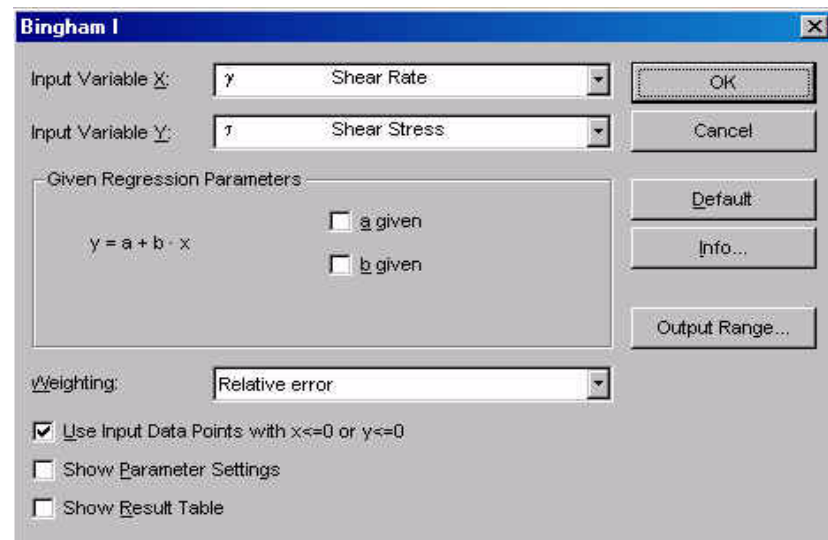


Fig. 5 - 16 Bingham I - Parameter settings

$$y = a + b \cdot x$$

x - input variable x
 y - input variable y
 a - yield stress (y-axis section)
 b - viscosity in the Newtonian region (curve slope)

5.9.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is the relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.9.2 Example

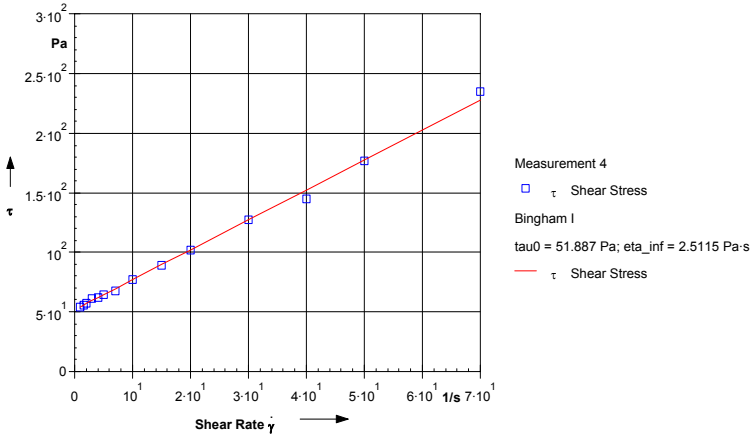


Fig. 5 - 17 Bingham I - Example

The example shows the flow curve of a ketchup. The yield stress is the shear stress at shear rate 0, the viscosity is the slope of the curve at the high shear rates.

5.10 Blau I

The Blau model has been developed to describe the viscosity curve of casting slip. It has a shear thinning region and an end zone with a constant viscosity.

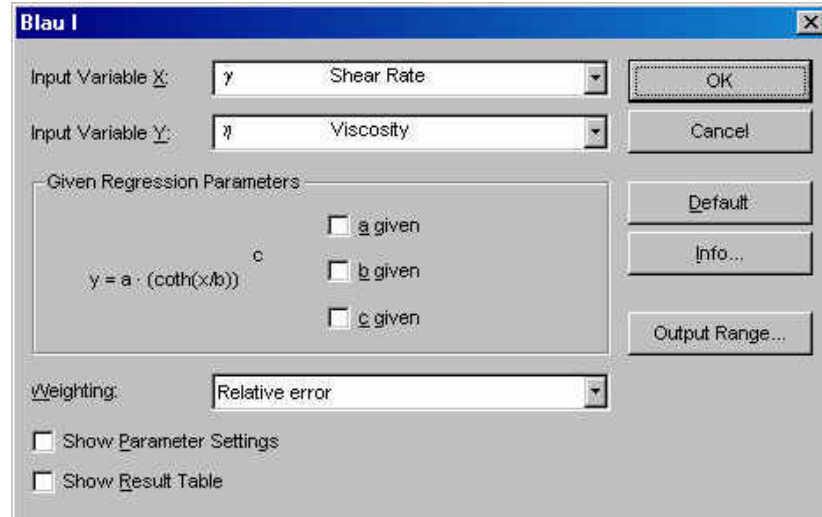


Fig. 5 - 18 Blau I - Parameter settings

$$y = a \cdot \left(\coth\left(\frac{x}{b}\right) \right)^c$$

x - input variable x
 y - input variable y
 a - factor for input variable y
 b - factor for input variable x
 c - coefficient for structure breakdown

5.10.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the viscosity is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.10.2 Example

The example below shows the viscosity curve from the measurement of a casting slip and the calculated Blau evaluation.

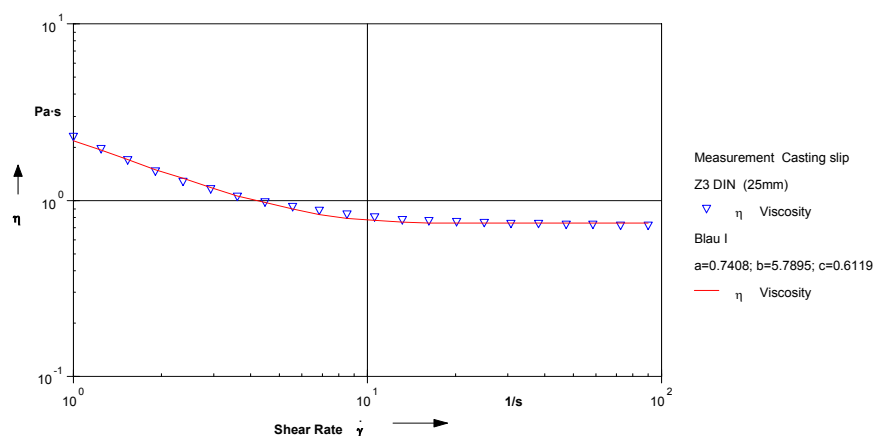


Fig. 5 - 19 Blau I - Example

5.11 Carreau I

The Carreau equation describes the viscosity curve of a material with Newtonian regions at low and at high shear rates and a shear thinning region at medium shear rates. This model is equivalent to the Carreau-Gahleitner equation with the parameter $b=2$.

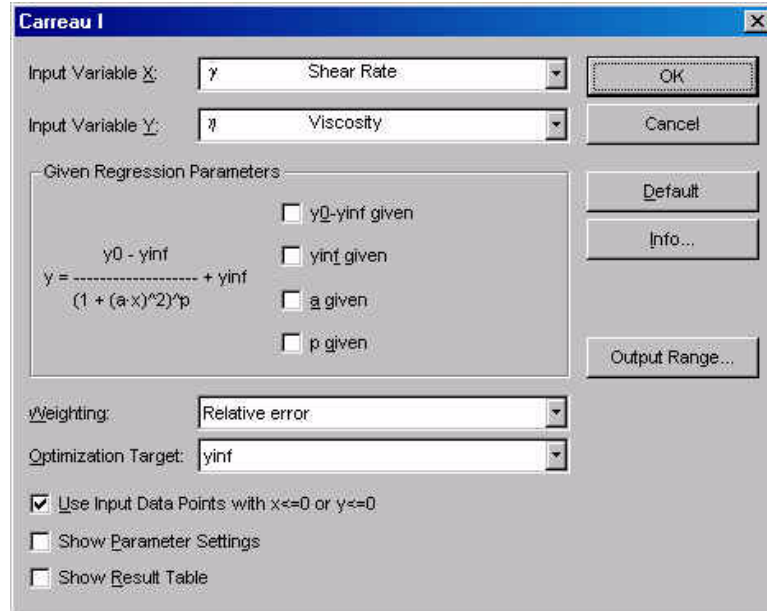


Fig. 5 - 20 Carreau I - Parameter settings

$$y = \frac{y_0 - y_{inf}}{(1 + (a \cdot x)^2)^p} + y_{inf}$$

x - input variable x
 y - input variable y
 y₀ - y value at x → 0 (zero shear viscosity)
 y_{inf} - y-value at x → ∞ (infinite viscosity)
 a - Carreau constant
 p - Carreau exponent

5.11.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the viscosity is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Optimization Target

The data evaluation can be optimized for 'yinf' or for 'ymin-yinf'. Which method gives the best results depends on the input data. To check which method is suitable for your data you can either display both measurement and evaluation in a diagram and observe the curve fit or compare the relative error in the result box of the analysis window. Usually, the optimization for 'yinf' will give better results if no second Newtonian region has been found in the measurement. If this region is present, the optimization 'ymin-yinf' should be used.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.11.2 Example

The example shows the viscosity curve of a biopolymer solution. The material shows a Newtonian region both at low and at very high shear rates. In between, shear thinning can be observed.

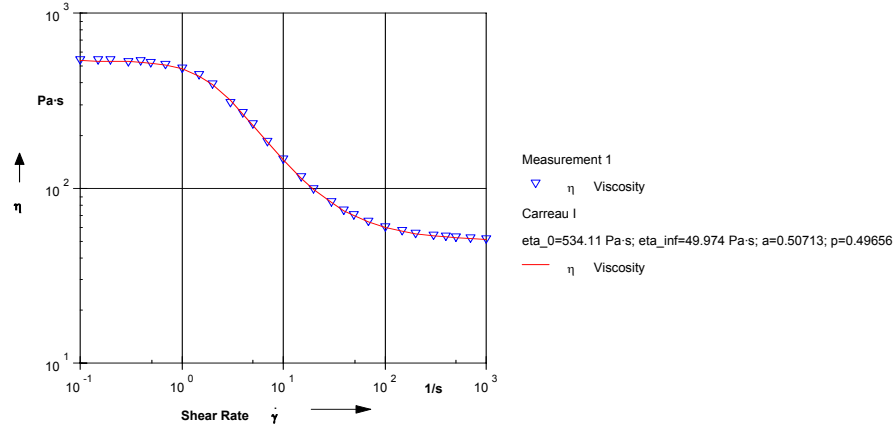


Fig. 5 - 21 Carreau I - Example

5.12 Carreau-Gahleitner I

The Carreau-Gahleitner equation describes the viscosity curve of a material with Newtonian regions at low and at high shear rates and a shear thinning region at medium shear rates. If the parameter b is equal to 2, this equation is identical with the Carreau model described in the previous chapter.

The screenshot shows the 'Carreau-Gahleitner I' dialog box. It has a title bar with a close button. The 'Input Variable X' is set to 'γ' (Shear Rate) and 'Input Variable Y' is set to 'η' (Viscosity). There are 'OK', 'Cancel', 'Default', and 'Info...' buttons on the right. The 'Given Regression Parameters' section contains a mathematical formula: $y = \frac{y_0 - y_{inf}}{(1 + (a \cdot x)^b)^p} + y_{inf}$. Below it, the 'Carreau' equation is shown: $y = (y_0 - y_{inf}) / (1 + (a \cdot x)^2)^p + y_{inf}$. There are checkboxes for 'y0-yinf given', 'yinf given', 'a given', 'b given' (checked with value 2), and 'p given'. The 'Weighting' is set to 'Relative error' and 'Optimization Target' is 'yinf'. There are also checkboxes for 'Use Input Data Points with x <= 0 or y <= 0', 'Show Parameter Settings', and 'Show Result Table'. An 'Output Range...' button is at the bottom right.

Fig. 5 - 22 Carreau-Gahleitner I - Parameter settings

$$y = \frac{y_0 - y_{inf}}{(1 + (a \cdot x)^b)^p} + y_{inf}$$

x - input variable x
 y - input variable y
 y_0 - y value at $x \rightarrow 0$ (zero shear viscosity)
 y_{inf} - y -value at $x \rightarrow \infty$ (infinite viscosity)
 a - Carreau constant
 b - Carreau exponent
 p - Carreau exponent

5.12.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x -variable is the independent variable, the y -variable is a function of x (dependent variable). As a default the shear rate is used as the x -variable, the viscosity is used as the y -variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Optimization Target

The data evaluation can be optimized for 'yinf' or for 'ymin-yinf'. Which method gives the best results depends on the input data. To check which method is suitable for your data you can either display both measurement and evaluation in a diagram and observe the curve fit or compare the relative error in the result box of the analysis window. Usually, the optimization for 'yinf' will give better results if no second Newtonian region has been found in the measurement. If this region is present, the optimization 'ymin-yinf' should be used.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.12.2 Example

The example shows the viscosity curve of a biopolymer solution. The material shows a Newtonian region at low shear rates and a pronounced shear thinning; the second Newtonian region cannot be observed.

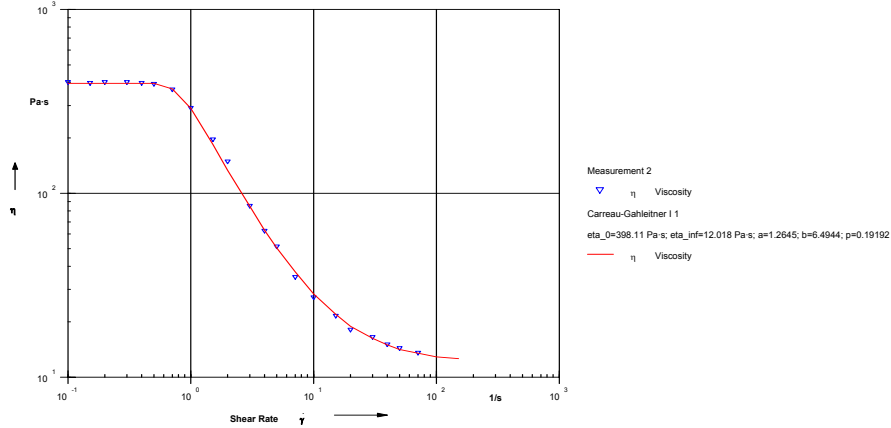


Fig. 5 - 23 Carreau-Gahleitner I - Example

5.13 Carreau-Yasuda I

The Carreau-Yasuda equation describes the viscosity curve of a material with Newtonian regions at low and at high shear rates and a shear thinning region at medium shear rates. It is, for example, used to fit a curve to the viscosity curve of blood.

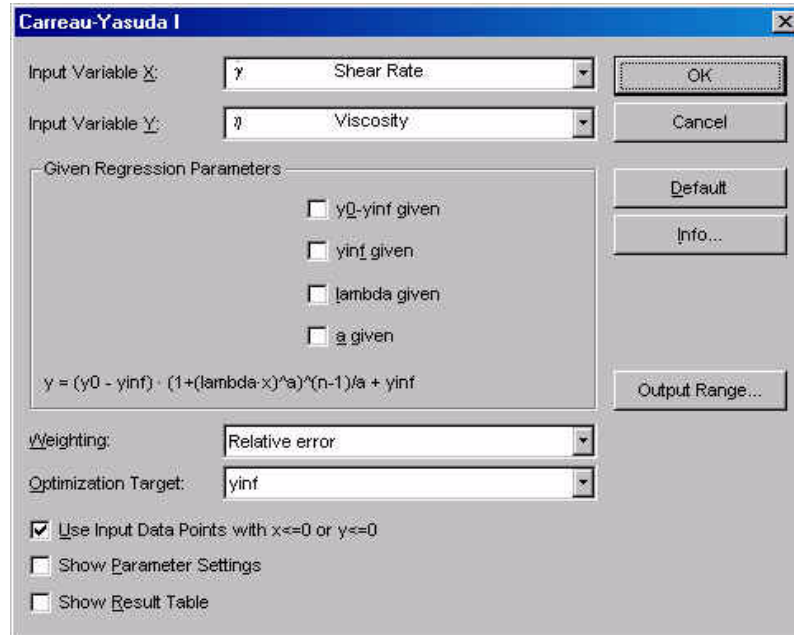


Fig. 5 - 24 Carreau-Yasuda I - Parameter settings

$$y = (y_0 - y_{inf}) \cdot (1 + (\lambda \cdot x)^a)^{\frac{n-1}{a}} + y_{inf}$$

x - input variable x
 y - input variable y
 y₀ - y value at x → 0 (zero shear viscosity)
 y_{inf} - y-value at x → ∞ (infinite viscosity)
 a - Carreau constant
 λ - relaxation time in s

5.13.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the viscosity is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Optimization Target

The data evaluation can be optimized for 'yinf' or for 'ymin-yinf'. Which method gives the best results depends on the input data. To check which method is suitable for your data you can either display both measurement and evaluation in a diagram and observe the curve fit or compare the relative error in the result box of the analysis window. Usually, the optimization for 'yinf' will give better results if no second Newtonian region has been found in the measurement. If this region is present, the optimization 'ymin-yinf' should be used.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.13.2 Example

The example shows the viscosity curve of a biopolymer solution. The material shows a Newtonian region at low shear rates and a pronounced shear thinning; the second Newtonian region cannot be observed.

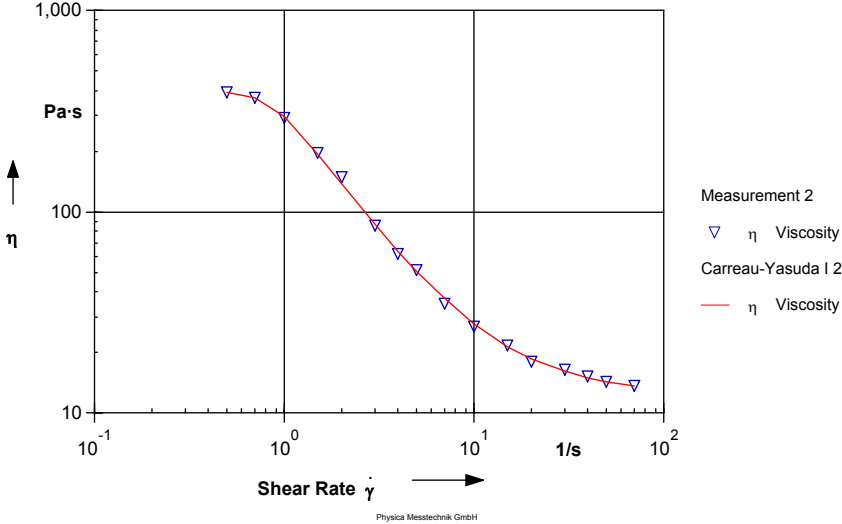


Fig. 5 - 25 Carreau-Yasuda I - Example

5.14 Casson I

The Casson equation describes the flow curve of a material with a yield stress and a non-Newtonian behaviour at stresses above the yield stress. It often provides a good fit for blood and for food products; it is often used for chocolate.

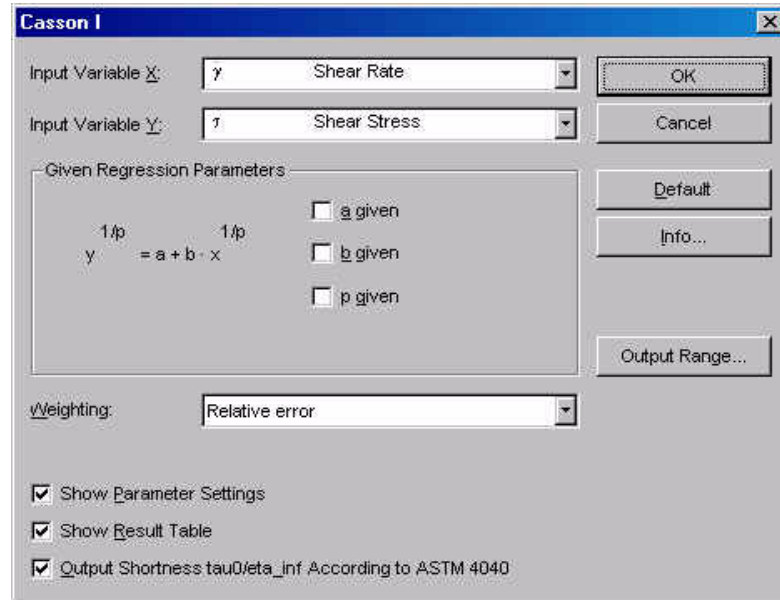


Fig. 5 - 26 Casson I - Parameter settings

$$y^{\frac{1}{p}} = a + b \cdot x^{\frac{1}{p}}$$

x - input variable x
 y - input variable y
 a - yield stress (y-axis section)
 b - Casson viscosity
 p - Casson exponent

In the standard Casson equation the exponent p has the value 2.

5.14.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

Output Shortness τ_0/η_{inf} according to ASTM 4040

With this option, the shortness, as calculated according to ASTM 4040, is stored in the result field of the data series and shown in the result window of the analysis.

5.14.2 Example

The example shows the flow curves and the Casson fit for two types of chocolate melt - dark and light. The light chocolate has a higher yield stress than the dark one and a higher viscosity. The Casson exponent is the same for both samples.

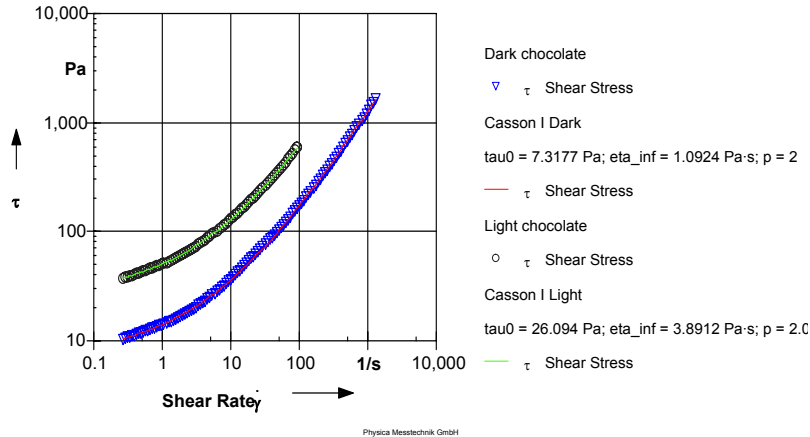


Fig. 5 - 27 Casson I - Example

5.15 Casson-Steiner I

The Casson-Steiner equation describes the flow curve of a material with a yield stress and a non-Newtonian behaviour at stresses above the yield stress. It often provides a good fit for blood and for food products; it is often used for chocolate.

It is similar to the Casson I equation but takes the radius ratio for concentric cylinder systems into account. For concentric cylinder systems according to DIN/ISO this ratio is 1.0847.

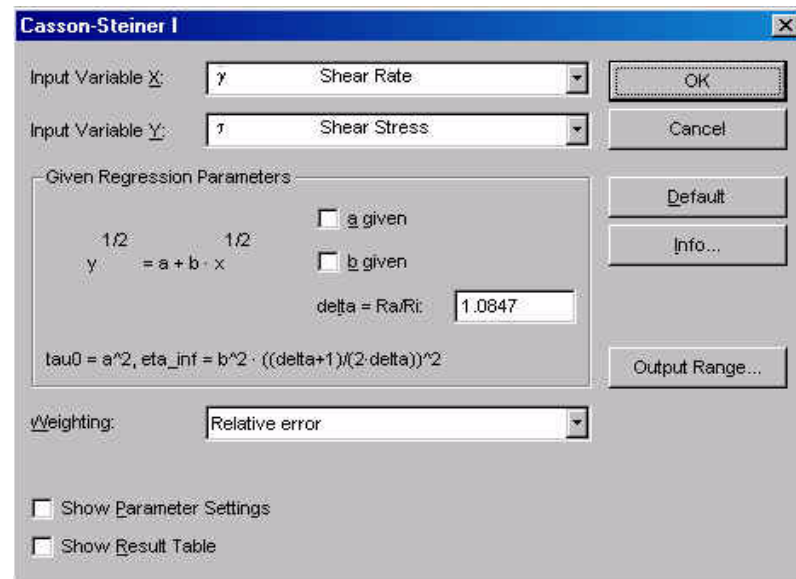


Fig. 5 - 28 Casson-Steiner I - Parameter settings

$$y^{\frac{1}{2}} = a + b \cdot x^{\frac{1}{2}}$$

$$\eta_{inf} = b^2$$

$$\tau_0 = a^2 \cdot \left(\frac{\delta + 1}{2 \cdot \delta}\right)^2$$

- x - input variable x
- y - input variable y
- a - yield stress (y-axis section)
- b - Casson viscosity
- η_{inf} - infinite viscosity
- τ₀ - yield stress
- delta - ratio outer radius / inner radius for concentric cylinder systems

5.15.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Given Regression Parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.15.2 Example

The example shows the flow curves and the Casson-Steiner fit for two types of chocolate melt - dark and light. The light chocolate has a higher yield stress than the dark one and a higher viscosity. The yield stress is given as the analysis result.

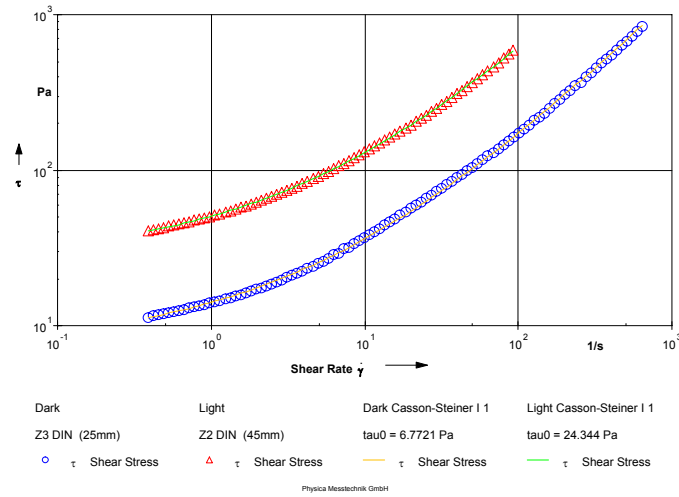


Fig. 5 - 29 Casson-Steiner I - Example

5.16 Cross I

The Cross model describes the viscosity curve of a material with a zero shear viscosity, a constant viscosity at high shear rate values and a shear thinning region in between. It is similar to the Carreau and Carreau-Gahleitner evaluation.

The Cross equation often fits well to polymer melts and to biopolymers. The second Newtonian region cannot necessarily be observed for these materials.

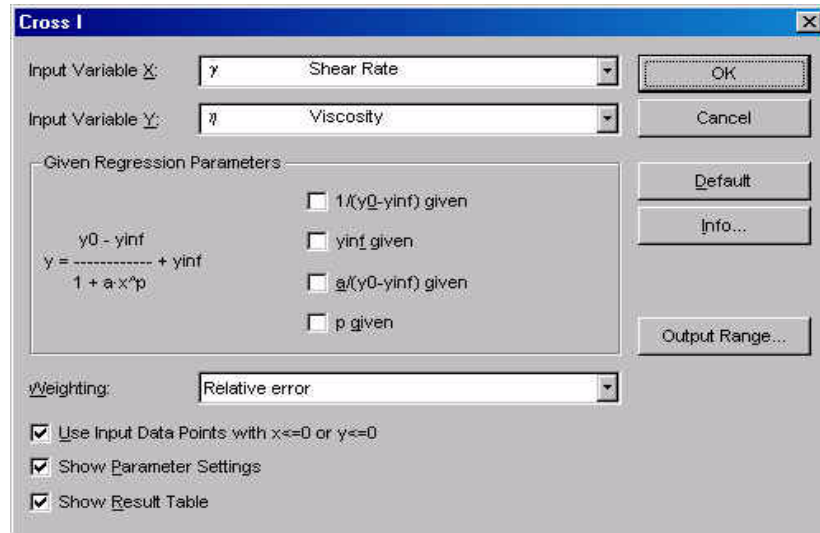


Fig. 5 - 30 Cross I - Parameter settings

$$y = \frac{y_0 - y_{inf}}{1 + a \cdot x^p} + y_{inf}$$

x - input variable x
 y - input variable y
 y₀ - y value at x → 0 (zero shear viscosity)
 y_{inf} - y-value at x → ∞ (infinite viscosity)
 a - Cross constant
 p - Cross exponent

5.16.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the viscosity is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.16.2 Example

The example shows the viscosity curves of two different polymer melts. For both samples the zero shear viscosity and the shear thinning region could be measured. The second Newtonian region could not be reached.

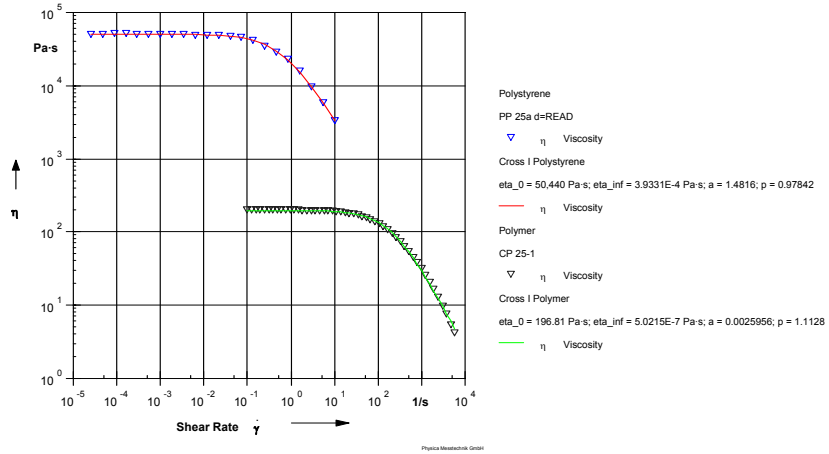


Fig. 5 - 31 Cross I - Example

5.17 Crossover

This method calculates the crossing point of the two selected y variables. This can e.g. be used to find the end of the linear viscoelastic region in an amplitude sweep (y: G' , G'' ; x: γ), to find the crossover frequency in a frequency sweep (y: G' , G'' ; x: frequency) or to find the gelling time or curing temperature (y: G' , G'' ; x: time or temperature).

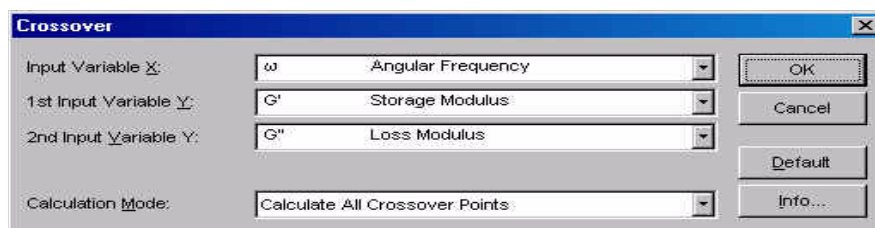


Fig. 5 - 32 Crossover - Parameter settings

5.17.1 Parameters and Default Settings

Input Variable X / 1st Input Variable Y / 2nd Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable).

Calculation Mode

Select whether to calculate all crossover points in a curve, or only the last / first crossover point that can be found. The detected crossover points will be stored with the default unit selected for the chosen x-variable.

5.18 Curve Parameters

The evaluation method 'Curve Parameters' is used to calculate local and global minima, local and global maxima, turning points and 1st and 2nd derivative of the selected input data. Further, the input data can be smoothed using different methods. The calculated values including the smoothed curve can be stored in the analysis result.

The screenshot shows the 'Curve Parameters' dialog box with the following settings:

- X-Variable: T (Temperature)
- X-Unit: K
- Y-Variable: tan(δ) (Damping Factor)
- Y-Unit: 1
- Curve Smoothing of Input Data: Smoothing with relative smoothing range (Smoothing Range: 1 % of Maximum)
- Values Shown in the Result Window of the Analysis Window:
 - Global Minimum
 - Global Maximum
 - Turning Points
 - Table with 1st and 2nd Derivative, Curvature
 - Local Minima
 - Local Maxima
- Data Points to be Stored in Output Data Series:
 - Global Minimum
 - Global Maximum
 - Turning Points
 - Smoothed Curve s(x)
 - Local Minima
 - Local Maxima
 - Derivatives, Curvature
- Show Parameter Settings

Fig. 5 - 33 Curve Parameters - Parameter settings (Example)

5.18.1 Parameter settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). There is no default setting for this analysis method.

Values shown in the Result Window of the Analysis Window

The selected values are shown in the result window after the analysis has been completed. The global minimum and maximum are single values. The local minima and maxima, the turning points, the derivatives and the curvature are shown as a table. If the number of local minima, maxima and turning points exceeds 30 only the first thirty values are listed. The data are not stored in the analysis result (data series) unless checked for below.

Data Points to be stored in Output Data Series

The calculated results as well as the smoothed curve can be stored in the output data series. All checked data are stored in the analysis result. Please note that all results are stored in a single output data series. In case you wish to have each result in a single series you need to repeat this analysis for each value.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

5.18.2 Curve Smoothing of Input Data

There are three smoothing methods available:

- Smoothing with relative smoothing range (default setting)
The smoothing range is entered in percent. The value is calculated as percent of the maximum y-value. It gives the maximum allowable difference between measured and calculated y-values.
- Smoothing with absolute smoothing range
For the smoothing range an absolute value of the y-variable is entered. The unit is the default unit of the selected variable.
- Automatic smoothing with smoothing criterion
If automatic smoothing is selected the smoothing starts with a range of 0% and is then increased in steps of 1% until the smoothing criterion is reached. The smoothing criterion can be the number of local maxima, of local minima or of turning points.

5.18.3 Example

The example shows the curing of a polymer sample. The smoothed curve has been calculated for the storage modulus and the damping factor, they are shown as lines in the diagram. Further, the global maximum of the damping factor and the turning point of the storage modulus have been calculated.

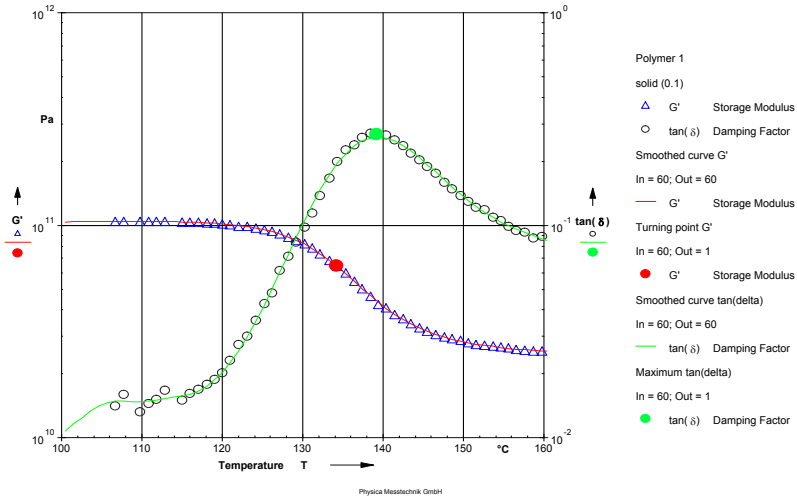


Fig. 5 - 34 Curve Parameters - Example

5.19 e-Function I

The e-Function model fits an exponential curve to the measurement data.

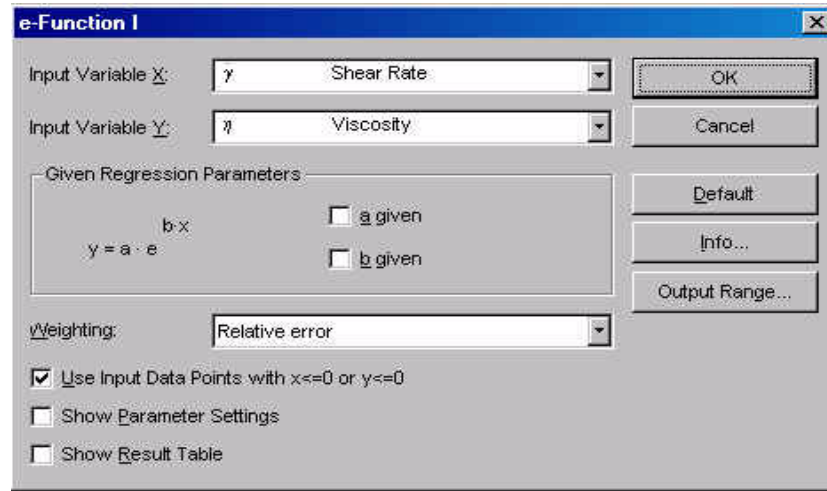


Fig. 5 - 35 e-Function I - Parameter settings

$$y = a \cdot e^{b \cdot x}$$

- x - input variable x
- y - input variable y
- e - Euler number
- a - factor
- b - exponent (negative for shear thinning material)

5.19.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the viscosity is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.19.2 Example

The figure below shows the viscosity curve of a shear thinning material with an e-function fit.

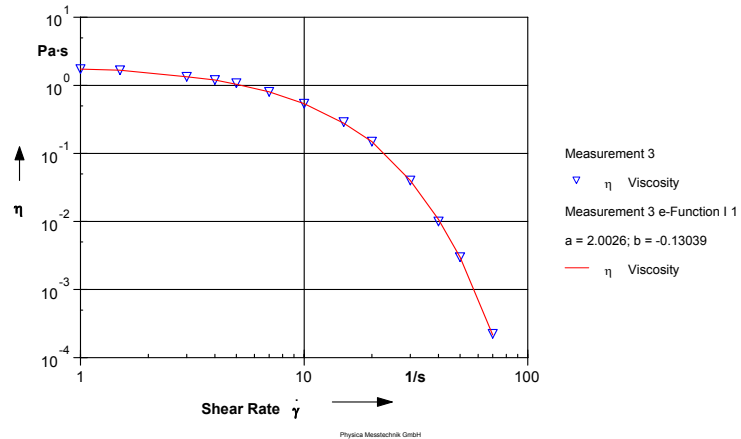


Fig. 5 - 36 e-Function I - Example

5.20 Ellis I

The Ellis model is often used to describe the flow behaviour of polymers, especially at low shear rates. It describes a material with a zero shear viscosity and a shear thinning region. The high shear rate range is not considered in this model.

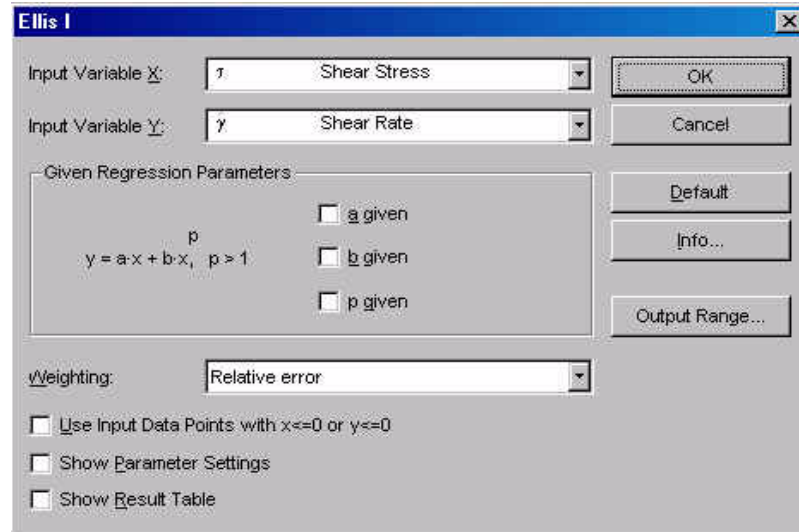


Fig. 5 - 37 Ellis I - Parameter settings

$$y = a \cdot x + b \cdot x^p \text{ with } p > 1$$

$$\eta_0 = \frac{1}{a}$$

$$c = \frac{1}{b}$$

x - input variable x
y - input variable y
a, b- factors
p - exponent

5.20.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear stress is used as the x-variable, the shear rate is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.20.2 Example

The figure below shows the viscosity curve of a polymer melt and the Ellis fit.

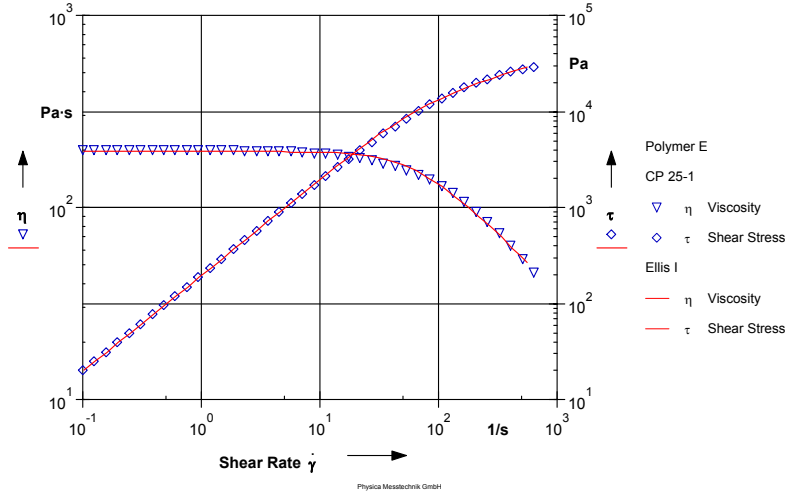


Fig. 5 - 38 Ellis I - Example

5.21 Eyring-Prandtl-Ree I

The Eyring-Prandtl-Ree equation describes the flow behaviour of a material whose viscosity is approaching a constant value for $\dot{\gamma} \rightarrow 0$. The model has been developed with the assumption that molecules change their position in the direction of the applied stress.

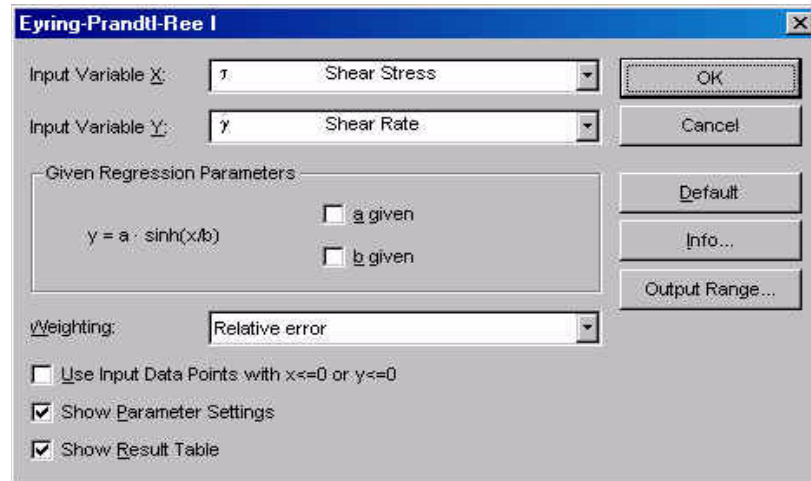


Fig. 5 - 39 Eyring-Prandtl-Ree I - Parameter settings

$$y = a \cdot \sinh\left(\frac{x}{b}\right)$$

- x - input variable x
- y - input variable y
- a - factor
- b - scaling factor

5.21.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear stress is used as the x-variable, the shear rate is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.21.2 Example

The example shows the flow curve of a polymer with a broad zero shear viscosity range and shear thinning behaviour at higher shear rates.

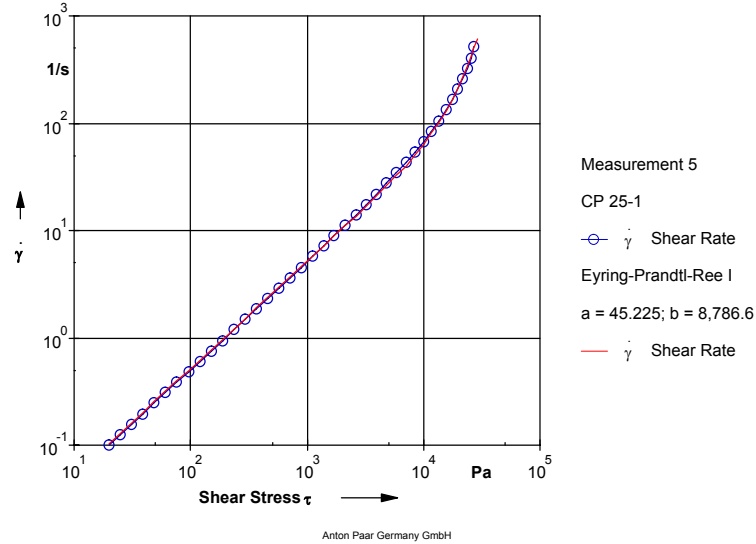


Fig. 5 - 40 Eyring-Prandtl-Ree I - Example

5.22 Herschel-Bulkley I

The Herschel-Bulkley model describes the flow curve of a material with a yield stress and shear thinning or shear thickening behaviour at stresses above the yield stress.

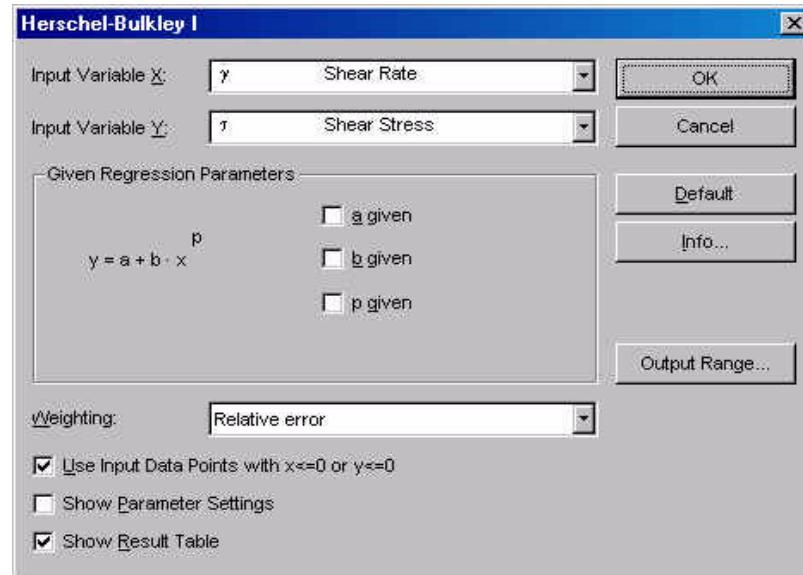


Fig. 5 - 41 Herschel-Bulkley I - Parameter settings

$$y = a + b \cdot x^p$$

- x - input variable x
- y - input variable y
- a - y-axis section
- b - factor
- p - coefficient

5.22.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.22.2 Example

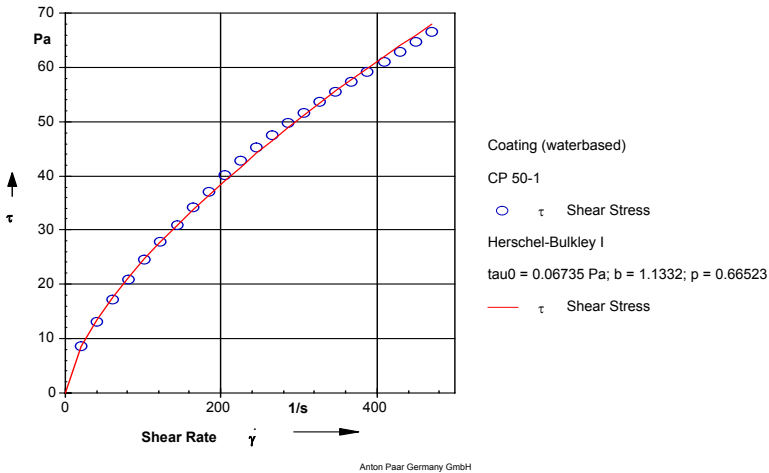


Fig. 5 - 42 Herschel-Bulkley I - Example

5.23 Hysteresis Area I

The evaluation method Hysteresis Area I calculates the area between two curves, commonly the up and down curve of a shear rate sweep. This area is given in [Pa/s] and is often used as a measure of a sample's thixotropy.

The screenshot shows a dialog box titled "Hysteresis Area I". It contains the following fields and controls:

- Set Variable X:** A dropdown menu showing "γ Shear Rate".
- Y-Variable:** A dropdown menu showing "τ Shear Stress".
- Sample Volume:** A text input field containing "1.143" and a unit dropdown showing "ml".
- A note: "(Measurement has been done with set variable d(gamma)/dt.)"
- Interval Numbers:** A section with two input fields: "Up Curve" containing "2" and "Down Curve" containing "4". To the right of these fields is the text: "Intervals must be separated by semicolons (e.g. 1;2;3)".
- Buttons: "OK", "Cancel", "Default", and "Info..."

Fig. 5 - 43 Hysteresis Area I - Parameter settings

5.23.1 Parameter settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Sample Volume

The sample volume is used to calculate the relative hysteresis area. It does not need to be entered for the calculation of the hysteresis area. The sample volume can be found in the edit dialog for the measuring systems (see 'Service I Measuring Systems I Edit' in the reference manual).

Interval numbers

The interval numbers for the up and down curve need to be entered correctly to make the calculation of the hysteresis area possible. They are the sections (intervals) from the measurement profile in which each curve has been defined. For an up-down sweep the interval numbers are 1 and 2, for a measurement with an up-hold-down profile the default setting can be used.

Please note that the complete data series has to be selected as input data. It is not possible to use sections of data series.

5.23.2 Example

The example shows the flow curves of two toothpaste samples measured in an up-hold-down profile. Toothpaste 1 (triangles) has a larger hysteresis area and therefore a slower recovery after shear.

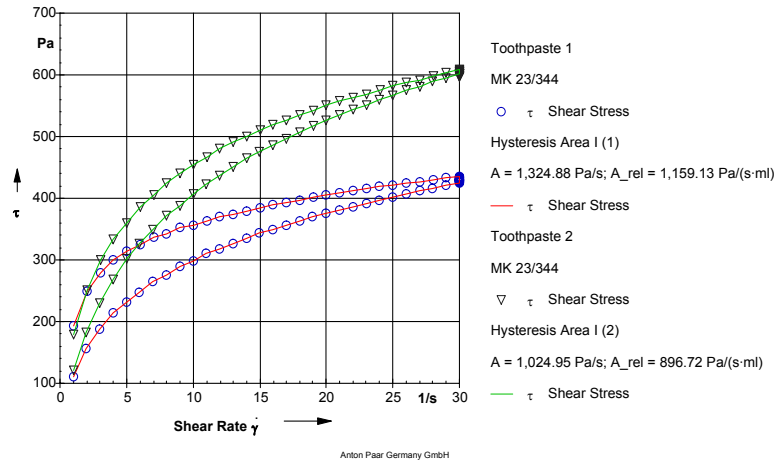


Fig. 5 - 44 Hysteresis Area I - Example

5.23.3 Calculation

The hysteresis area is calculated as follows:

$$A_{hyst} = \left| \sum_{i=1}^{n-1} A_{i, up} - \sum_{i=1}^{n-1} A_{i, down} \right|$$

$$A_{hyst,rel} = \frac{A_{hyst}}{V}$$

$$A_i = \frac{1}{2} \cdot [(x_{i+1} - x_i) \cdot (y_i + y_{i+1})]$$

n-number of input data points

V-sample volume in [ml]

x-input variable x (shear rate in [1/s])

y-input variable y (shear stress in [Pa])

A_{hyst} -hysteresis area in [Pa/s]

$A_{hyst,rel}$ -relative hysteresis area in [Pa/(s·ml)]

5.24 Integration

With the Integration analysis you can calculate the area under a curve, i.e. between a curve and the x-axis.

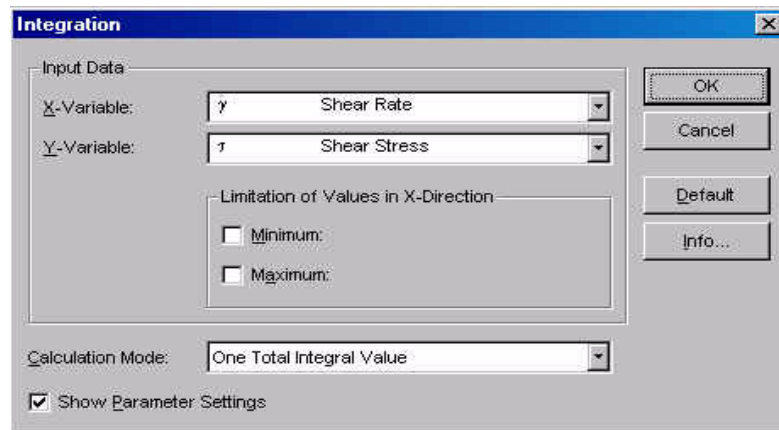


Fig. 5 - 45 Integration - Parameter settings

5.24.1 Parameter settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). The evaluation can be used for all variables. The integration analysis uses the default units of the variables as defined in the main window.

Limitation of Values in X-Direction

'Minimum' and 'Maximum' give the range of x-values for which the integration area is to be calculated. It is not necessary to enter measured values; the software will calculate the values by linear interpolation in case values are selected that are not in the measurement data.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

5.25 IOCCC 2000 / Windhab

This analysis method is generally used for the evaluation of flow curves from chocolate and other cocoa products. It is recommended by the 'International Office of Cocoa, Chocolate and Sugar Confectionery'.

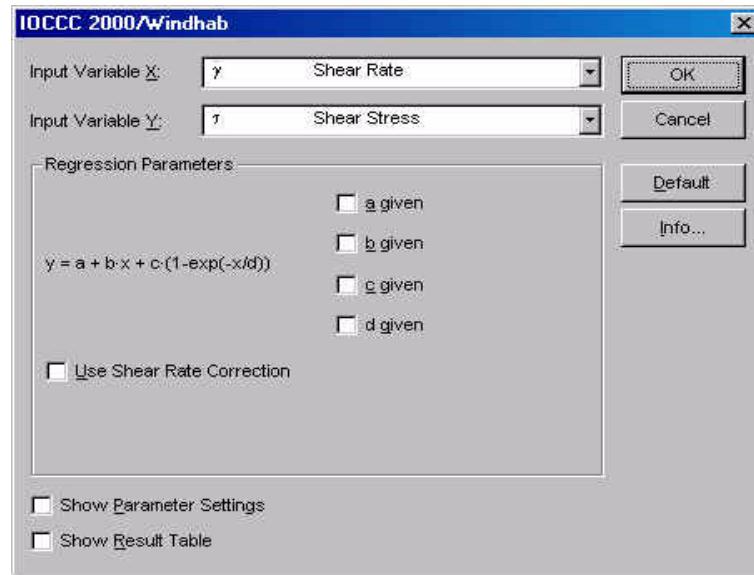


Fig. 5 - 46 IOCCC 2000 / Windhab - Parameter settings

$$y = a + b \cdot x + c \cdot \left(1 - e^{-\left(\frac{x}{d}\right)} \right)$$

- x - input variable x
- y - input variable y
- a - y-value for x=0
- b - slope at x → ∞
- c - coefficient
- d - exponent

For the standard parameters (x-variable: shear rate; y-variable: shear stress) the regression parameters have the following meaning:

- a - real yield stress τ_0
- b - infinite viscosity
- a + c- linear yield stress
- d - characteristic shear rate D^*

5.25.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear stress is used as the x-variable, the shear rate is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Use Shear Rate Correction

If the shear rate correction is activated the shear rate values are re-calculated. The correction takes the strongly non-Newtonian behaviour of chocolate into account. The ratio is the ratio outer to inner radius of the concentric cylinder system. The equation is described under 'Info' in the parameter dialog box of this analysis method.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.25.2 Example

The example shows the flow curves of a dark and a light chocolate (symbols) and the curves (lines) that have been calculated using the evaluation method IOCCC 2000 / Windhab. The analysis result contains a linear yield stress, a viscosity value for $\dot{\gamma}$ and a characteristic shear rate D^* .

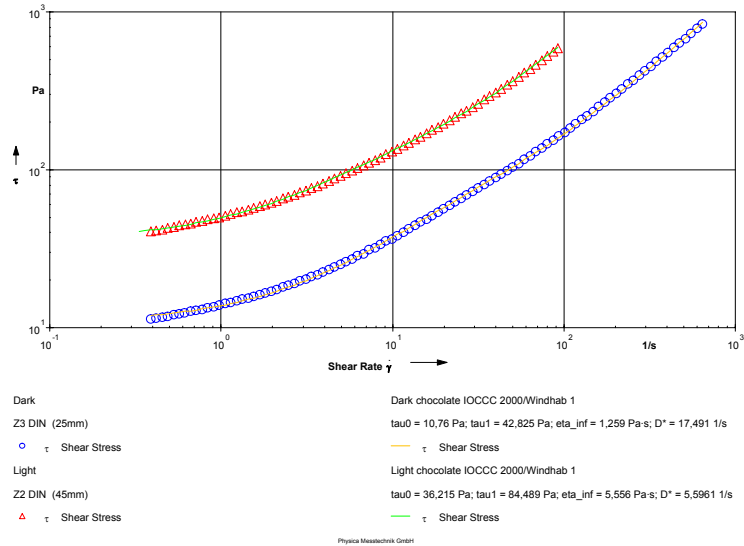


Fig. 5 - 47 IOCC 2000 / Windhab - Example

5.26 Krieger-Dougherty I

The Krieger-Dougherty model describes the viscosity curve of a material with a zero shear viscosity at low stresses and shear thinning behaviour at higher stresses. It is often used to describe the behaviour of suspensions.

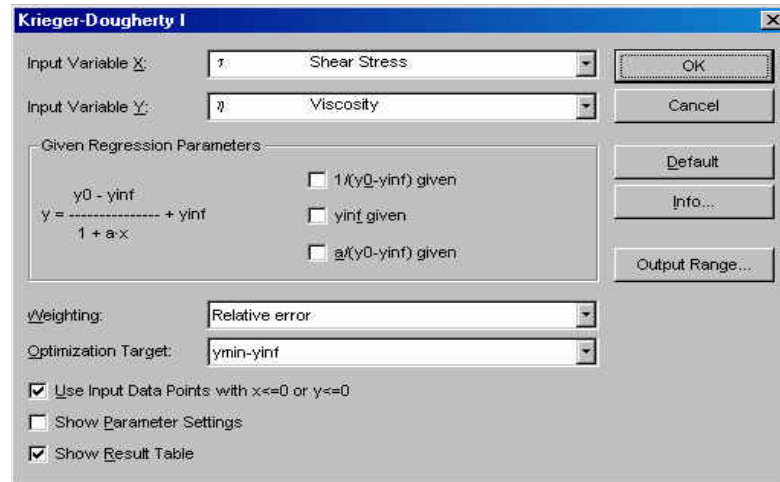


Fig. 5 - 48 Krieger-Dougherty I - Parameter settings

$$y = \frac{y_0 - y_{inf}}{1 + (a \cdot x)} + y_{inf}$$

$$\tau_c = \frac{1}{a}$$

x - input variable x
 y - input variable y
 y₀ - y value at x → 0 (e.g. zero shear viscosity)
 y_{inf} - y-value at x → ∞ (e. g. infinite viscosity)
 a - constant
 τ_c - critical shear stress

5.26.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the viscosity is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Optimization Target

The data evaluation can be optimized for 'yinf' or for 'ymin-yinf'. Which method gives the best results depends on the input data. To check which method is suitable for your data you can either display both measurement and evaluation in a diagram and observe the curve fit or compare the relative error in the result box of the analysis window. Usually, the optimization for 'yinf' will give better results if no second Newtonian region has been found in the measurement. If this region is present, the optimization 'ymin-yinf' should be used.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.26.2 Example

The example shows the viscosity curve of a suspension and the Krieger-Dougherty fit.

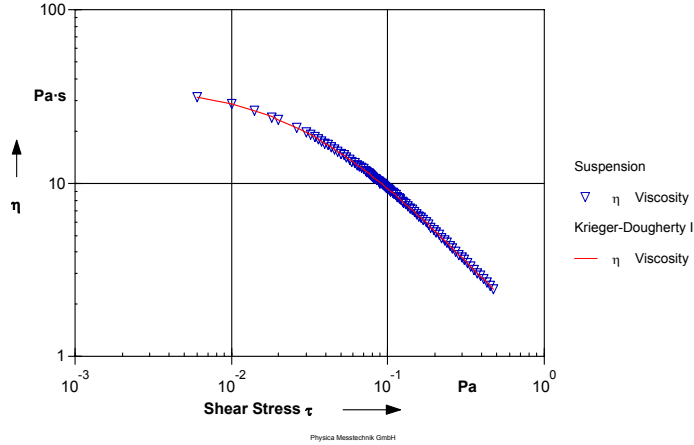


Fig. 5 - 49 Krieger-Dougherty I - Example

5.27 LVE Range

'LVE Range' can be used to determine the end of the linear viscoelastic region in an amplitude sweep. The evaluation includes several criteria for the determination of this value. Further, a smoothing of the measurement data can be carried out prior to the evaluation. This analysis method also suggests a strain value that should not be exceeded in subsequent measurements.

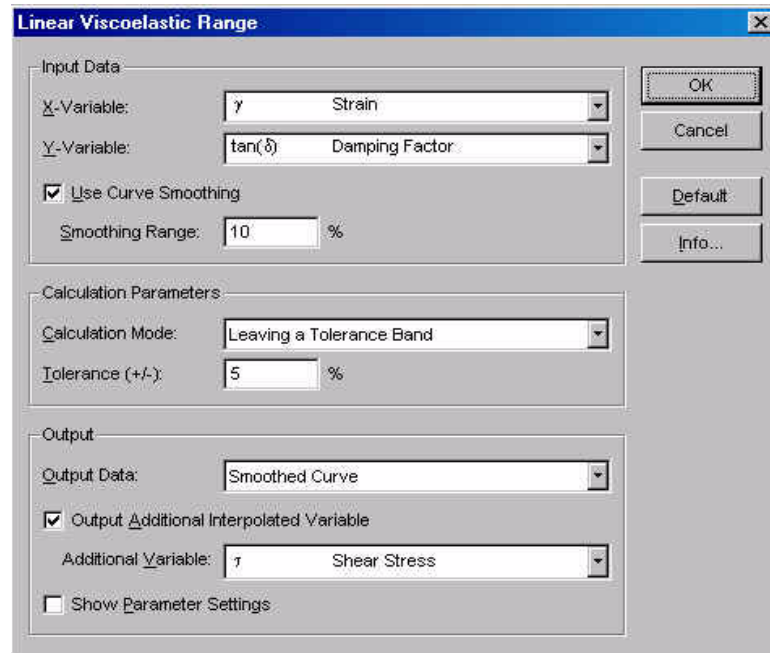


Fig. 5 - 50 Linear Viscoelastic Range - Parameter settings

5.27.1 Parameter settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). The evaluation can be used for all variables. As x-variable usually strain or shear stress is selected; as y-variable the damping factor, the loss angle or the storage modulus are suitable values.

Use Curve Smoothing / Smoothing Range

Check the option 'Use Curve Smoothing' to smooth the measurement data prior to the LVE evaluation. This option is recommended if the input data are noisy to avoid errors in the calculation of the end of the linear viscoelastic range. The smoothing range gives the maximum deviation (in %) of the smoothed data from the input data.

Output Additional Interpolated Variable

Check this option to calculate an additional variable at the LVE boundary (and proposal), e.g. the shear stress at the end of the linear viscoelastic region.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

5.27.2 Calculation Parameters

Leaving a Tolerance Band

The analysis method checks whether the data are inside the tolerance range given in the 'Tolerance +/-' box. When the selected y-variable is outside the tolerance, the end of the linear region has been found.

Detect an Upward Deflection / Detect a Downward Deflection

The end of the linear region is detected as a change of the curve of the selected y-variable from a line fitted to the measurement data. Usually, upward deflection is selected if the y-variable is the damping factor or the loss angle, downward deflection is chosen for e.g. the storage modulus.

Please note that the analysis also works on data that show a sloping 'linear region' not only data where the linear region is parallel to the x-axis as it should be.

5.27.3 Output

Proposal (single point)

The result of the analysis is a recommended value of the x-variable, usually the strain, for subsequent measurements.

LVE Range Boundary (single point)

The result of the analysis is the value of the x-variable where the end of the linear viscoelastic region has been reached.

LVE Range Boundary and Proposal (single point)

The result of the analysis are both the end of the linear viscoelastic region and a recommended value for the x-variable.

Smoothed Curve

The result of the analysis is a smoothed curve of the input data. The output data series only contains the values of the x- and y-variable.

Note that all single-point output values are given in the default unit as defined in the main window of the Rheoplus software ('Options | Default Units').

5.27.4 Example

The example shows amplitude sweeps for two different adhesives. The samples differed greatly in the level of the storage modulus and in the linear viscoelastic range. Adhesive 1 (hollow symbols) is linear up to a strain of 0.0153 (1.53 %) whereas Adhesive 2 (filled symbols) already starts to break down at a strain of 0.0026 (0.26 %). The end of the linear region and the proposal are shown as hollow squares in the diagram. For Adhesive 2 the smoothed curve for the damping factor is shown as well.

The proposed strain values are 0.01 (1 %) and 0.001 (0.1 %) respectively.

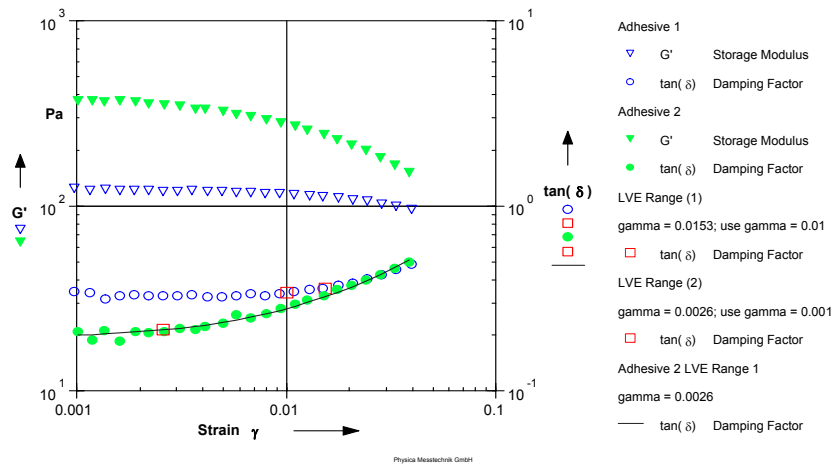


Fig. 5 - 51 LVE Range - Example

5.28 Monitor Data -> t_per

This analysis method is used to calculate the raw deflection angle and the raw torque from the data stored with the monitor window (software option). The monitor window can only show the data during a measurement, to display the data in a standard diagram, the measurement data series needs to be analysed with this method. The method has no parameter settings, only the input data series has to be selected.

5.28.1 Example

The example shows the raw deflection angle for the first data points in an oscillatory time test. For the measurement, no adjusting time or mean value building time has been set to be able to observe the adjusting process. If the torque is shown as a function of the deflection angle, you get the so-called Lissajous figure.

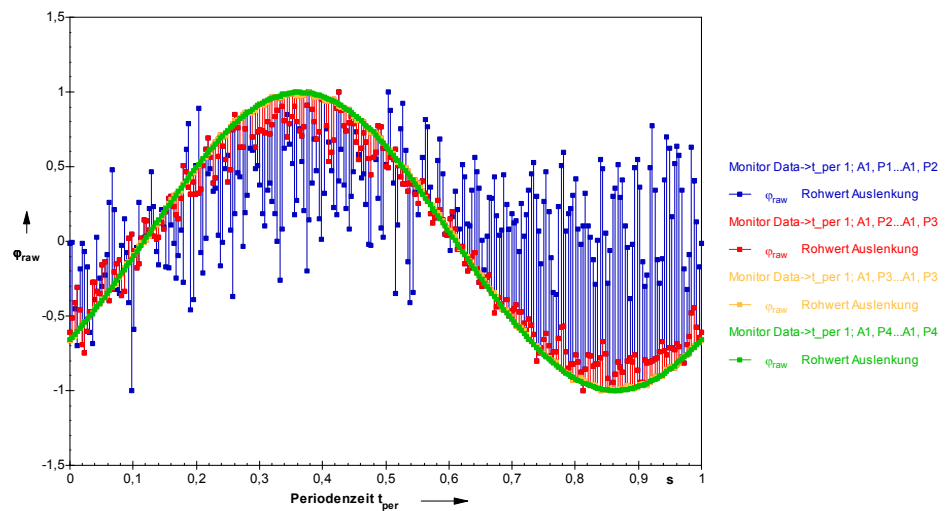


Fig. 5 - 52 Example - Monitor Data -> t_per

5.29 Newton I

The Newton equation describes the flow curve of a material with a constant i.e. shear rate independent viscosity. The flow curve is a straight line through the origin, the slope of the curve is the viscosity.

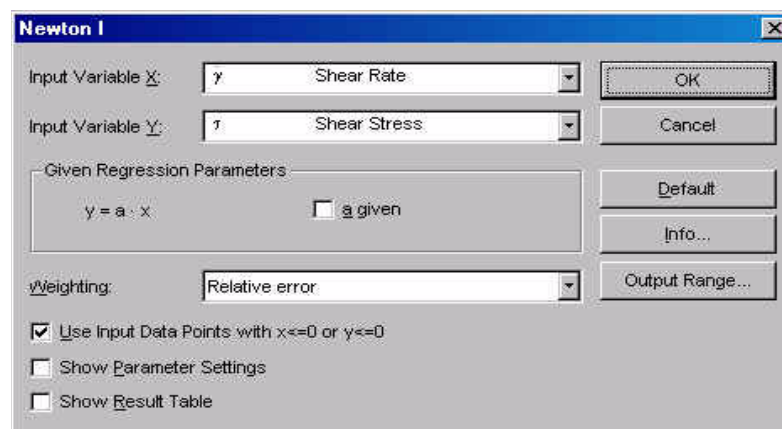


Fig. 5 - 53 Newton I - Parameter settings

$$y = a \cdot x$$

- x - input variable x
- y - input variable y
- a - slope (viscosity)

5.29.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.29.2 Example

There are few Newtonian materials, examples are oil (as shown in the diagram), syrup, water and solvents.

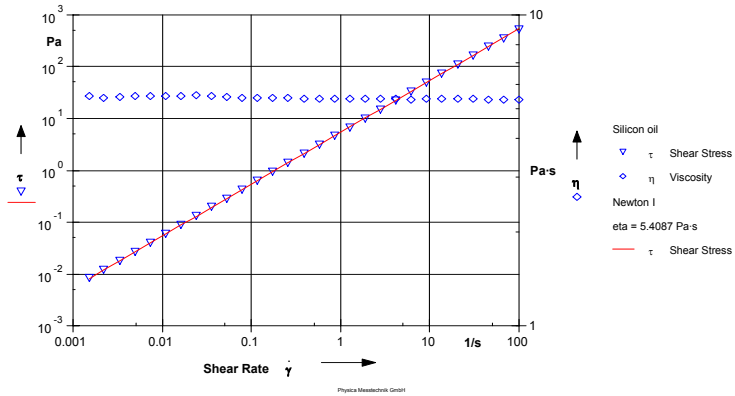


Fig. 5 - 54 Newton I - Example

5.30 Ostwald I

The Ostwald I model can be used to represent the flow curves of shear thinning or shear thickening materials. If the exponent b is equal to one, the equation is identical to the Newton model. For a shear thinning material b is smaller than one and larger for shear thickening materials.

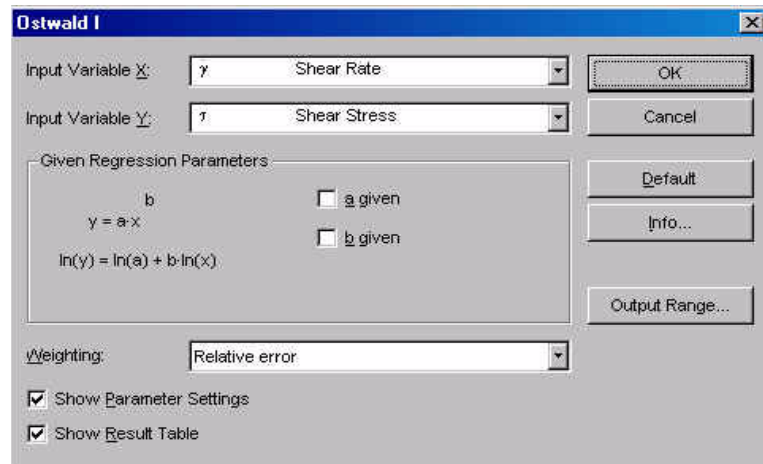


Fig. 5 - 55 Ostwald I - Parameter settings

$$y = a \cdot x^b$$

- x - input variable x
- y - input variable y
- a - factor
- b - exponent

5.30.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.30.2 Example

The example shows the flow and viscosity curve of a paste, a shear thinning material. In a log-log diagram the curve is a straight line with the slope b (in this case $b < 1$).

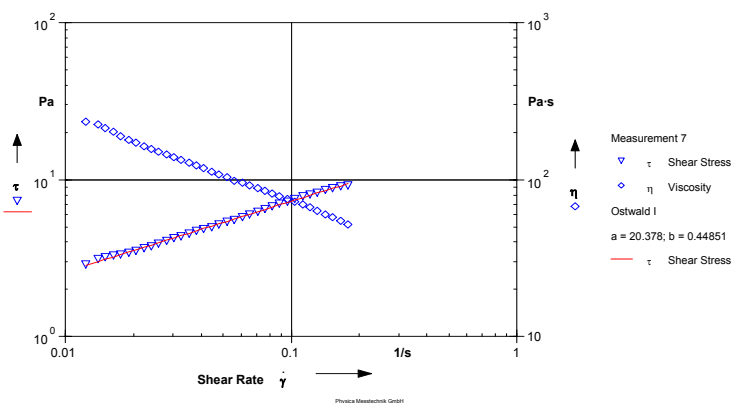


Fig. 5 - 56 Ostwald I - Example

5.31 Phillips-Deutsch I

The Phillips-Deutsch model describes the flow curve of a material that has two Newtonian regions, one at very low shear rates and one at high shear rates. In between, the material is shear thinning. This model is similar to the models Carreau and Carreau-Gahleitner.

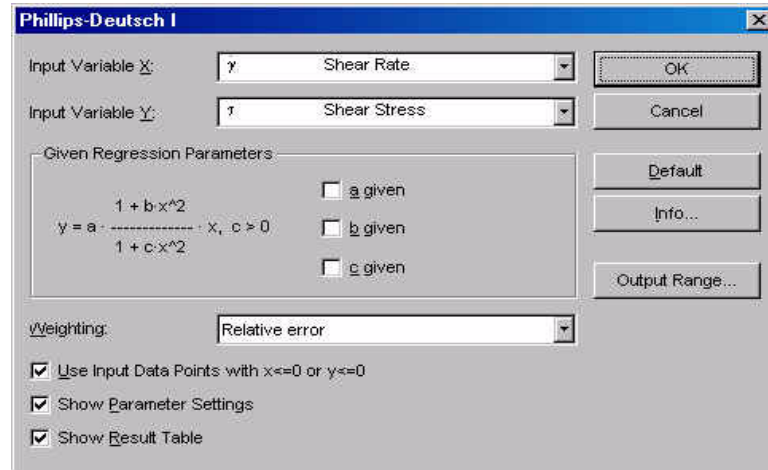


Fig. 5 - 57 Phillips-Deutsch I - Parameter settings

$$y = a \cdot \frac{1 + b \cdot x^2}{1 + c \cdot x^2} \cdot x$$

- x - input variable x
- y - input variable y
- a - factor
- b - numerator coefficient
- c - denominator coefficient

5.31.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.31.2 Example

The example shows the flow and the viscosity curve of a polymer with two Newtonian regions. The factor a gives the viscosity in the first Newtonian region, the viscosity in the second Newtonian regions is calculated as $a.b/c$.

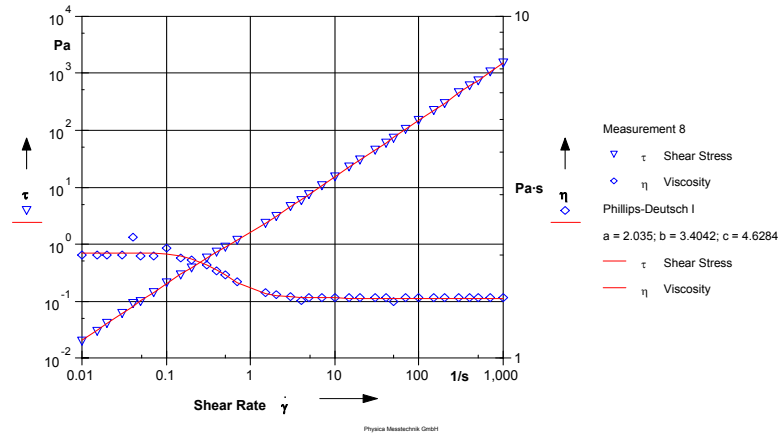


Fig. 5 - 58 Phillips-Deutsch I - Example

5.32 Quemada I

The Quemada model is commonly used to evaluate measurements on blood and serum.

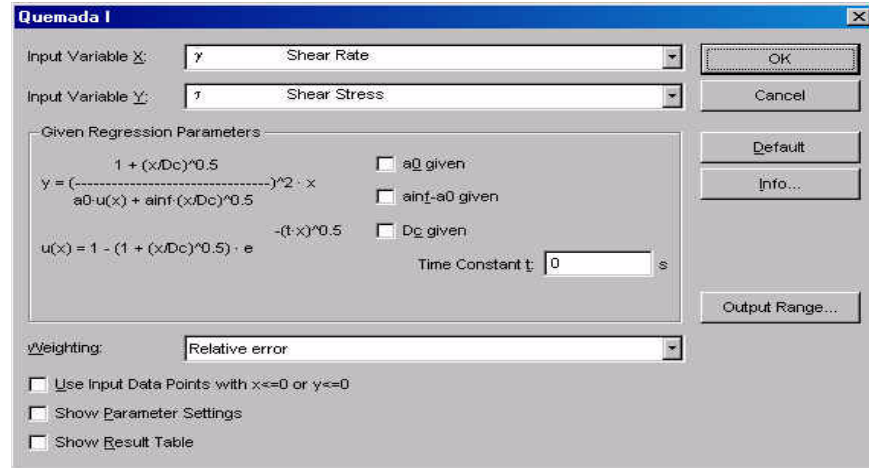


Fig. 5 - 59 Quemada I - Parameter settings

$$y = \left(\frac{1 + \left(\frac{x}{D_c}\right)^{0,5}}{a_0 \cdot j(x) + a_{inf} \cdot \left(\frac{x}{D_c}\right)^{0,5}} \right)^2 \cdot x$$

with:

$$u(x) = 1 - \left(1 + \left(\frac{x}{D_c}\right)^{0,5} \cdot e^{-(t \cdot x)^{0,5}} \right)$$

- x - input variable x
- y - input variable y
- a0 - Quemada factor 1
- ainf- Quemada factor 2
- Dc- critical x-value
- t - time constant (should be 0)

5.32.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data). Please note that the Quemada model cannot be used for negative values, therefore disable this option.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.32.2 Example

The example shows a measurement on blood with a start viscosity of about 100 mPa·s and an approach to a Newtonian region at high shear rates.

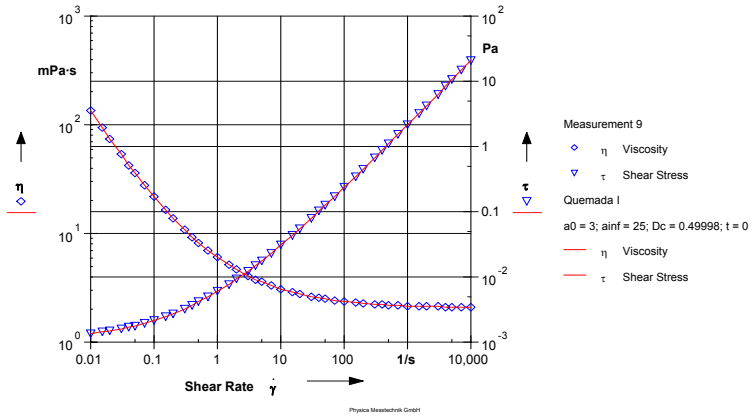


Fig. 5 - 60 Quemada I - Example

5.33 Result Field

The method 'Result Field' can be used to display a value from the input curve in the legend of this curve in a diagram or the table header. The pair of values of the first data point in the input curve is used for this method.

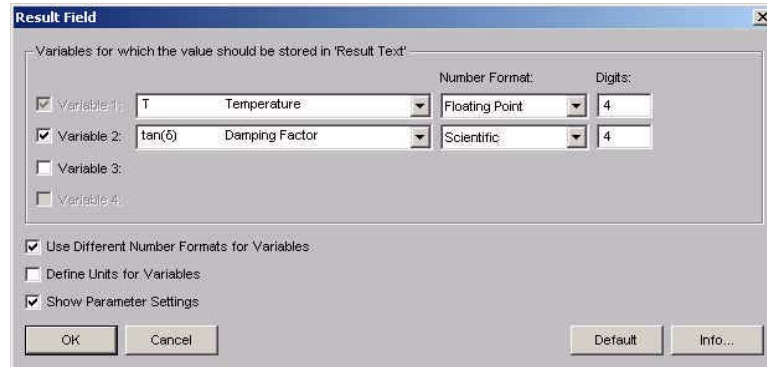


Fig. 5 - 61 Result Field - Parameter settings

5.33.1 Parameters and Default Settings

Variable 1, 2, 3, 4

Select the required variables from the lists.

Number Format

Select the number format in the drop-down list. You can choose between 'Floating Point', 'Scientific' and 'Mixed'.

Use Different Number Formats for Variables

Check this option if you would like to use different number formats when several variables are selected. If this option is not checked, all variables will use the same number format.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

5.33.2 Example

The example shows storage and loss modulus and $\tan \delta$ of a polymer. For the damping factor a smoothed curve and the global maximum have been calculated using the evaluation method 'Curve Parameters' (see there). The method 'Result Field' has then been applied to the analysis result to present the temperature and the damping factor value of the global maximum in the legend of the diagram.

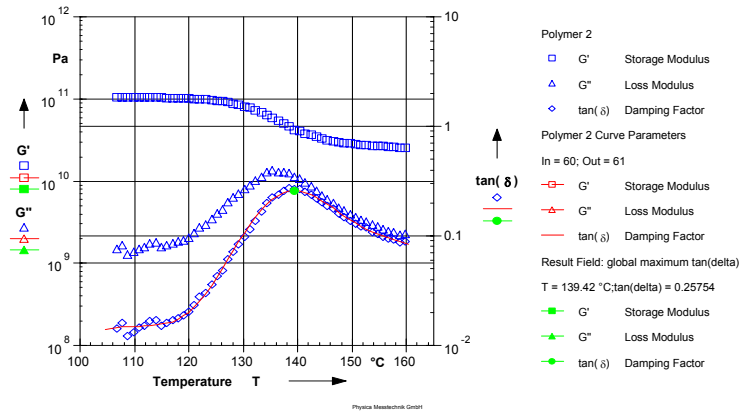


Fig. 5 - 62 Result Field - Example

5.34 Sisko I

The Sisko I model describes the behaviour of a material with a shear thinning and a Newtonian region at high shear rates.

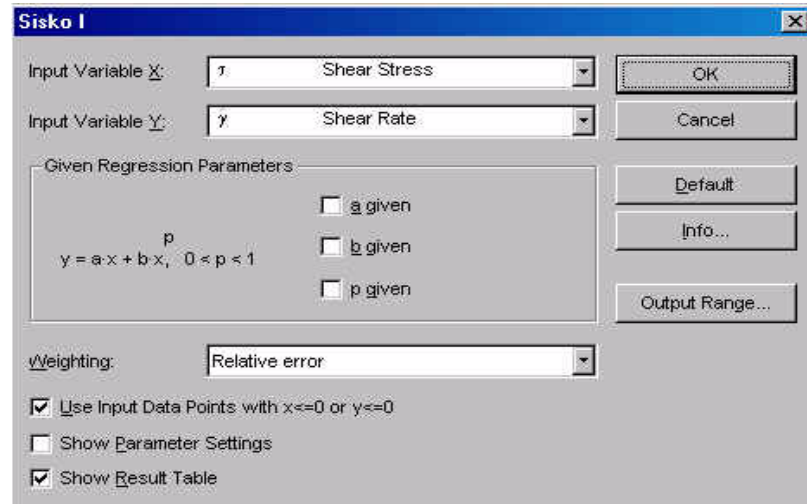


Fig. 5 - 63 Sisko I - Parameter settings

$$y = a \cdot x + b \cdot x^p$$

with: $0 < p < 1$

$$\eta_{\infty} = \frac{1}{a} \text{ and } c = b$$

x - input variable x
y - input variable y
a - coefficient
b - coefficient
p - exponent

5.34.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear stress is used as the x-variable, the shear rate is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data). Please note that the Quemada model cannot be used for negative values, therefore disable this option.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.34.2 Example

The example shows the shear rate as a function of the shear stress for a polymer solution. The Sisko I fit has been applied to shear stresses above 1000 Pa.

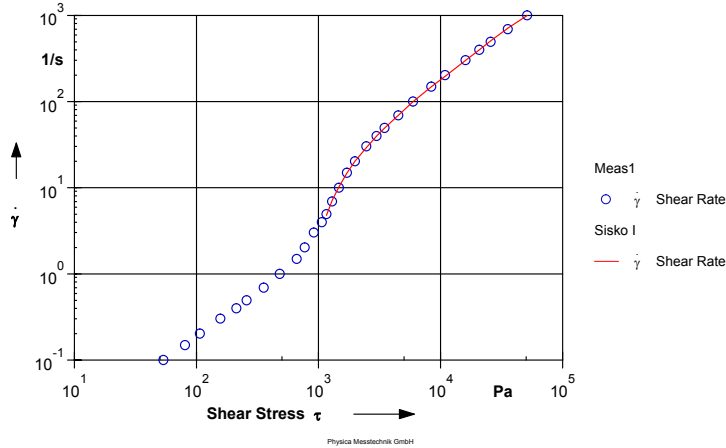


Fig. 5 - 64 Sisko I - Example

5.35 Slope

This method can be used to calculate the slope of any curve. The calculation can be done in linear or logarithmic scale.

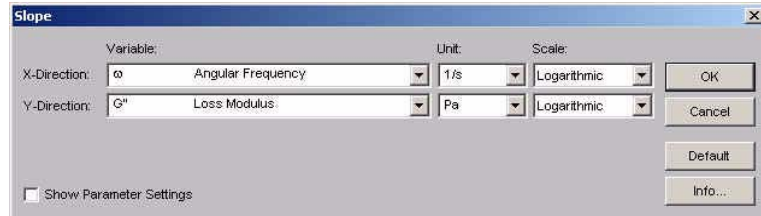


Fig. 5 - 65 Slope - Parameter settings

5.35.1 Parameters and Default Settings

X-Direction / Y-Direction

Select the x and the y variable from the list. Further, select the unit of the variables and the scaling type. Calculation of the slope can be done in lin-lin, lin-log, log-lin or log-log scaling.

5.35.2 Example

The example shows the slope for the storage and the loss modulus at low frequencies in a frequency sweep on a polymer sample.

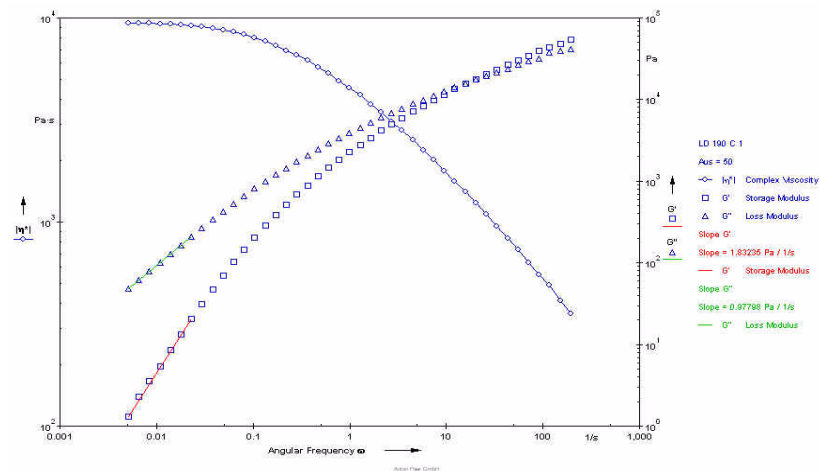


Fig. 5 - 66 Slope - Example

5.36 Smoothing

'Smoothing' can be used to remove noise from measurement data. The method allows the simultaneous smoothing of several input variables. Further, the data can be re-distributed; the number of points in the result curve can be selected by the user.

The smoothing is done by a natural cubic spline interpolation.

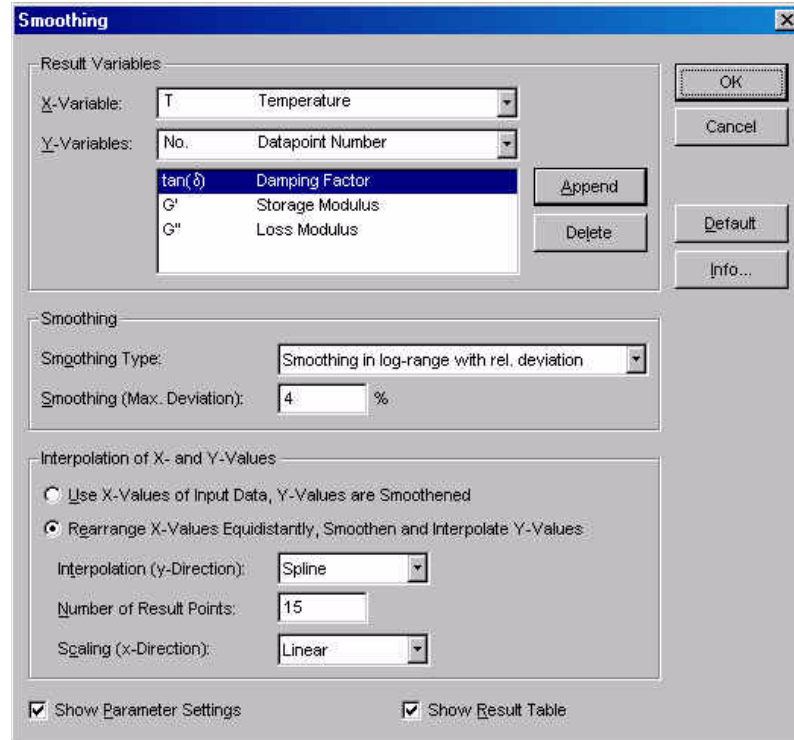


Fig. 5 - 67 Smoothing - Parameter settings

5.36.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.36.2 Smoothing

Data can either be smoothed with relative or with absolute deviation, both in linear and in logarithmic scaling.

If absolute deviation is selected the interpolation is done in such a way that the maximum deviation of the smoothed curve from the original curve is the value entered as 'Smoothing (Max. Deviation)'. This method can only be used if a single y-variable has been selected, it cannot be applied to several variables simultaneously. As a unit the default unit of the Rheoplus as defined in the main window is used.

If relative deviation is used, the maximum deviation is entered in percent and calculated as percentage of the maximum value of the selected variable in the input curve. With this method, several variables can be smoothed at a time.

With logarithmic scaling only positive y-values are used, negative values are ignored. If logarithmic scaling is selected, the input values are first transformed to logarithmic scale, smoothed and recalculated to linear scale.

5.36.3 Interpolation of X- and Y-values

- **Use X-Values of Input Data, Y-Values are Smoothened**
With this option the output data series contains the same x-values, value and number, as the input data series, only the y-values are smoothed.
- **Rearrange X-Values Equidistantly, Smoothen and Interpolate Y-Values**
If this option is selected you can define how many data points the output data series should have. The data points are distributed evenly, either logarithmic or linear, between start and end value of the x-variable. The corresponding y-values are calculated through interpolation.

Select the interpolation method (cubic spline or linear) for the y-values, enter the number of points for the output data series and enter the scaling type. For the interpolation method cubic spline is used as a default. The scaling type depends on the scaling required for the presentation of the output data series.

5.36.4 Example

The example shows the measured and the smoothed curves for a polymer sample. The values for G' , G'' and the damping factor have been smoothed with 3%, the x-values were re-arranged, setting 15 data points.

The smaller the maximum deviation, the more closely will the smoothed data follow the original curve. You have to find a value that gives optimum smoothing without hiding significant changes in the input data. If the value selected for the maximum deviation in the example is too large, the curve maximum of e. g. the damping factor may be different in the smoothed curve. Further, if the number of points is too small the maximum 'disappears'.

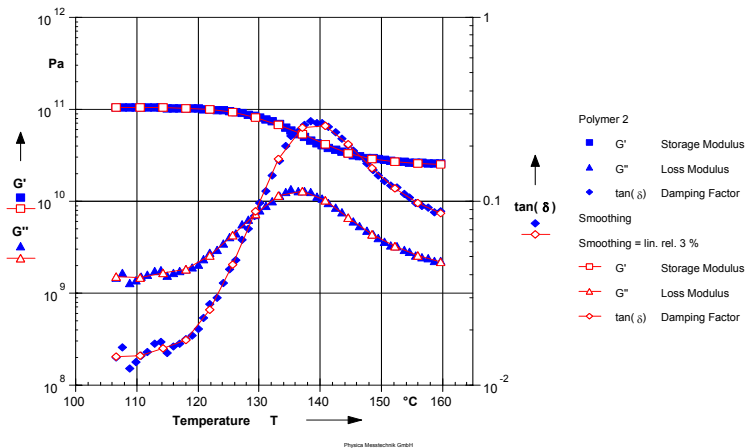


Fig. 5 - 68 Smoothing - Example

5.37 Steiger Ory I

The Steiger-Ory equation describes shear thinning materials.

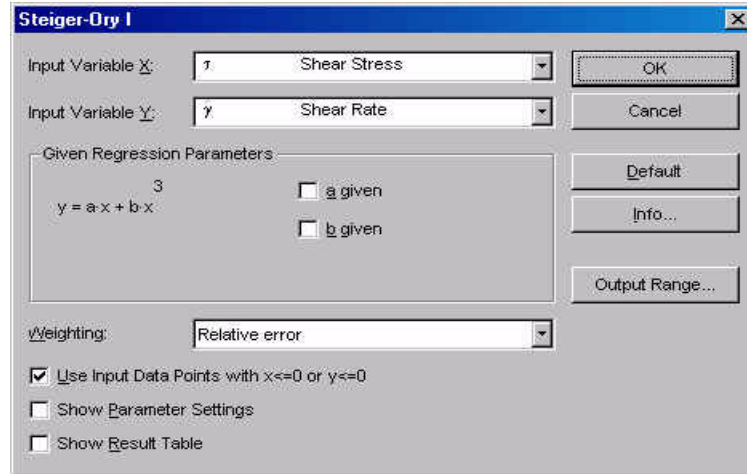


Fig. 5 - 69 Steiger-Ory - Parameter settings

$$y = a \cdot x + b \cdot x^3$$

- x - input variable x
- y - input variable y
- a - Steiger-Ory coefficient 1
- b - Steiger-Ory coefficient 2

5.37.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear stress is used as the x-variable, the shear rate is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data). Please note that the Quemada model cannot be used for negative values, therefore disable this option.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.37.2 Example

The example shows the measurement data and analysis of a paste. The sample has a Newtonian region at low shear rates; then it shows shear thinning behaviour.

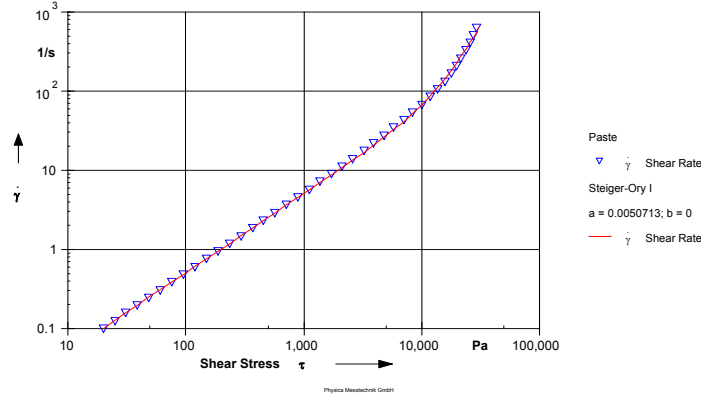


Fig. 5 - 70 Steiger-Ory I - Example

5.38 Stettin I

The Stettin evaluation can be used to describe the temperature dependency of a material where the Arrhenius equation does not give a good correlation between measured and calculated values.

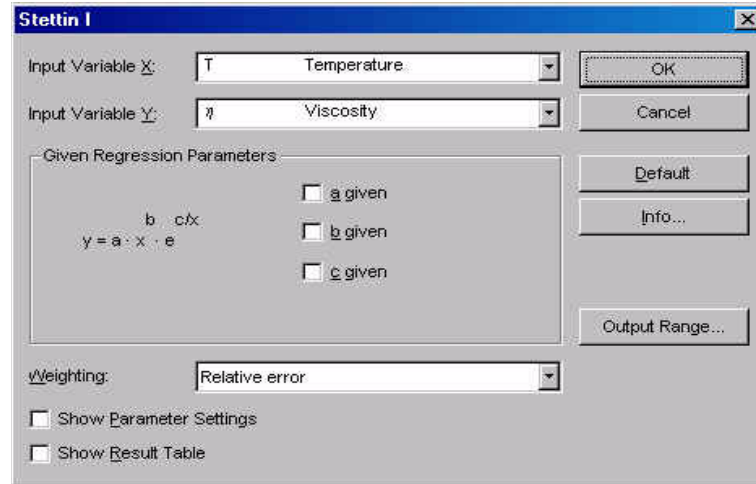


Fig. 5 - 71 Stettin I - Parameter settings

$$y = a \cdot x^b \cdot e^{\frac{c}{x}}$$

- x - input variable x
- y - input variable y
- a - coefficient
- b - exponent 1
- c - exponent 2

5.38.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the temperature is used as the x-variable, the viscosity is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.38.2 Example

The example shows the temperature dependence of the viscosity of a viscosity standard, a Newtonian oil.

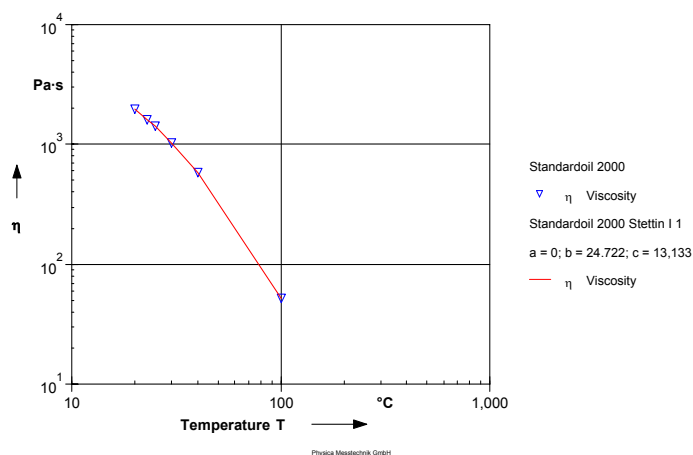


Fig. 5 - 72 Stettin I - Example

5.39 Temperature I

This evaluation method can be used to describe the temperature dependency of a material where the Arrhenius equation does not give a good correlation between measured and calculated values.

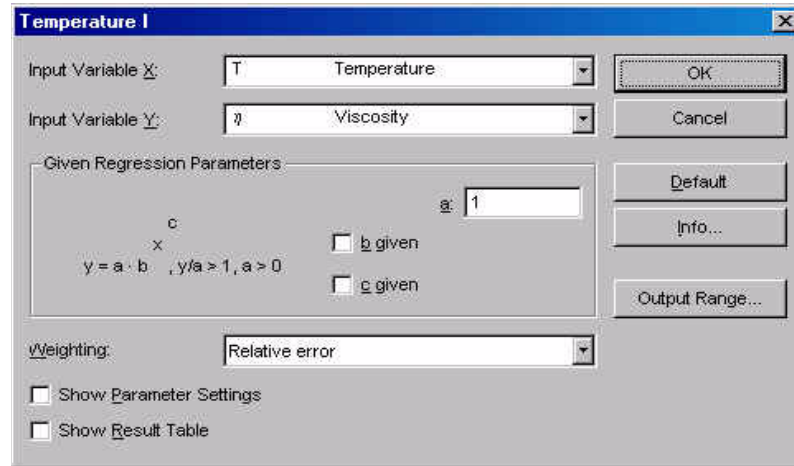


Fig. 5 - 73 Temperature I - Parameter settings

$$y = a \cdot b^{x^c}$$

with:

$$\frac{y}{a} > 1 \text{ or } a < \text{Min}(y) \text{ and } a > 0$$

- x - input variable x
- y - input variable y
- a - coefficient 1
- b - coefficient 2
- c - exponent

5.39.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the temperature is used as the x-variable, the viscosity is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.39.2 Example

The example shows the temperature dependency of the viscosity of a silicon oil.

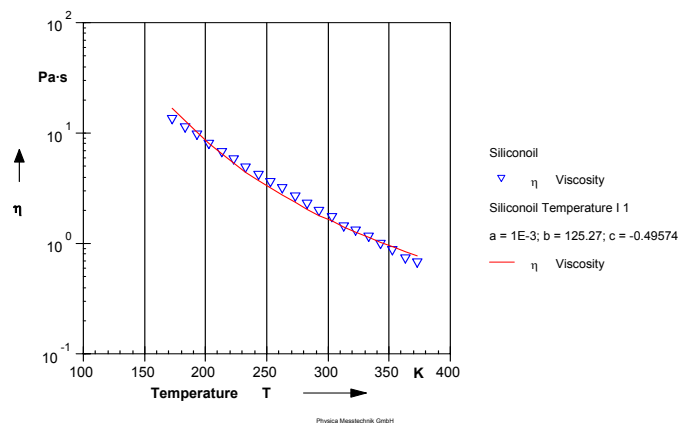


Fig. 5 - 74 Temperature I - Example

5.40 Tscheuschner I

The Tscheuschner I evaluation has been developed to describe the flow behaviour of chocolate in a broader range than the Casson equation.

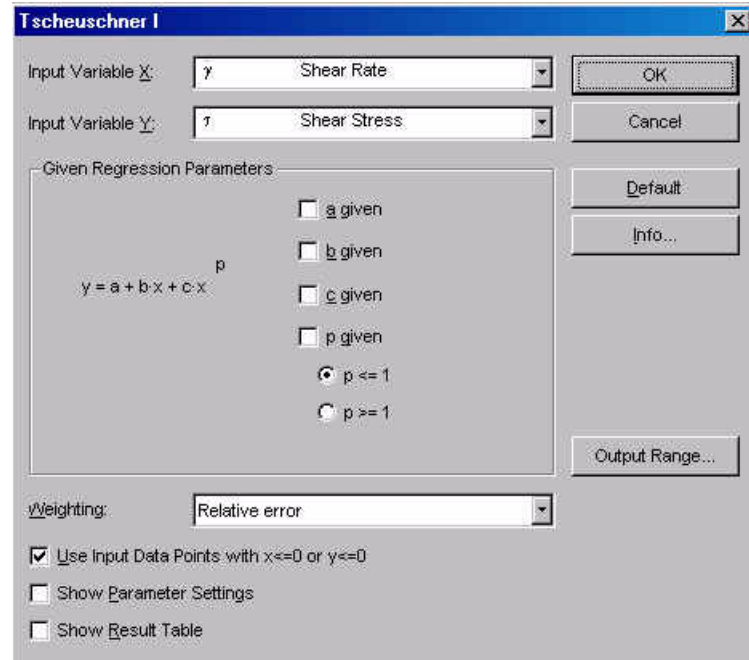


Fig. 5 - 75 Tscheuschner I - Parameter settings

$$y = a + b \cdot x + c \cdot x^p$$

- x - input variable x
- y - input variable y
- a - y-value for x=0
- b - slope at x → ∞
- c - coefficient
- p - exponent

5.40.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.40.2 Example

The example shows the flow and viscosity curve of a dark chocolate. The Tscheuschner evaluation calculates a yield stress for the material and a viscosity value at $\dot{\gamma} \rightarrow \infty$. Further, a structure-related viscosity share is calculated.

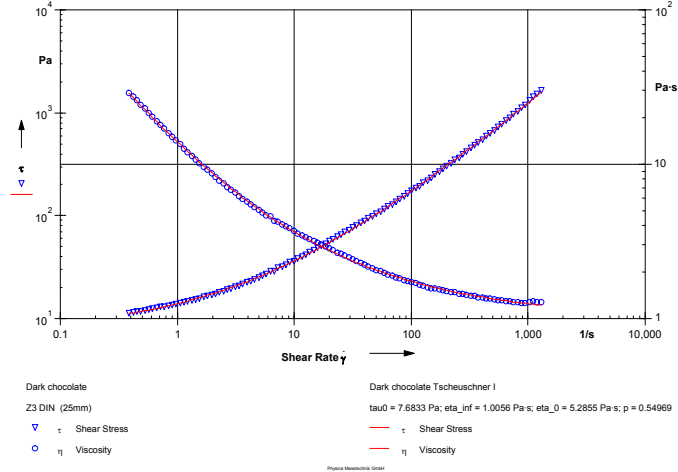


Fig. 5 - 76 Tscheuschner I - Example

5.41 Vinogradov-Malkin I

The Vinogradov-Malkin I equation describes the viscosity curve of a material with a zero shear viscosity value and a shear thinning region. The model can be optimized for different parameters (see 'Optimization Target') depending on the sample behaviour.

Fig. 5 - 77 Vinogradov-Malkin I - Parameter settings

$$y = \frac{y_0 - y_{inf}}{1 + a \cdot x^p + b \cdot x^{2p}} + y_{inf}$$

- x - input variable x
- y - input variable y
- a - coefficient 1
- b - coefficient 2
- p - exponent

5.41.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Optimization Target

The evaluation of the Vinogradov-Malkin model can be optimized for the y-value at infinite x-values or for the difference between the value of the y-variable at the minimum x-values and the value of the y-variable at infinite x-values.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.41.2 Example

The example shows the flow curve of a silicon with a high molecular weight (106). This material shows a Newtonian region at low and medium shear rates and shear thinning behaviour at high shear rates.

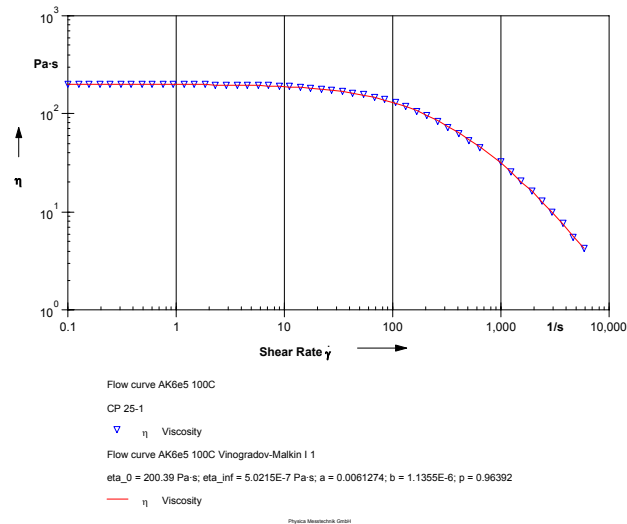


Fig. 5 - 78 Vinogradov-Malkin I - Example

5.42 Visco-Temp ASTM D 341-03

This method is used to calculate the temperature dependence of the kinematic viscosity of fluid petroleum products according to ASTM D 341-03.

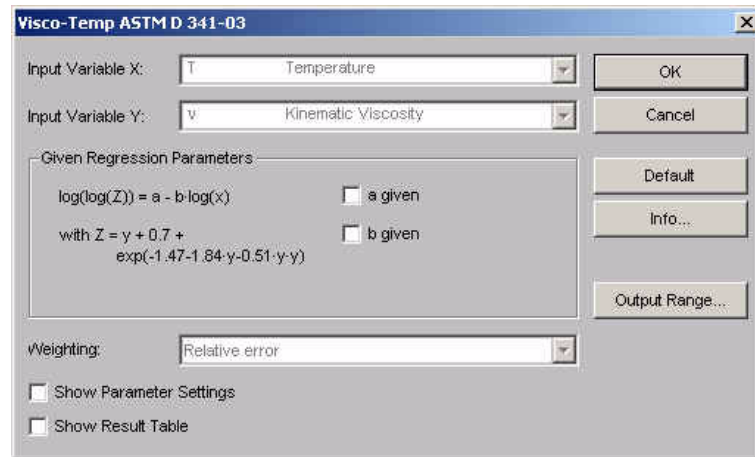


Fig. 5 - 79 Visco-Temp ASTM 341-93 - Parameter settings

$$\log(\log(Z)) = a - (b \cdot \log(x))$$

with:

$$Z = y + 0,7 + \exp(-1,47 - (1,84 \cdot y) - (0,51 \cdot y^2))$$

x - input variable x
 y - input variable y
 a - coefficient 1
 b - coefficient 2

5.42.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the temperature in K is used as the x-variable, the kinematic viscosity in mm²/s is used as the y-variable.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.42.2 Example

The example shows the calculated viscosity curve for a motor oil.

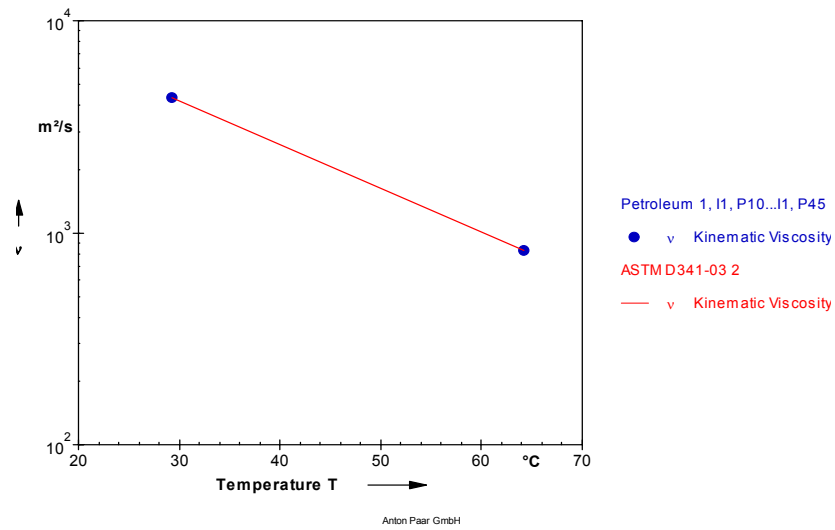
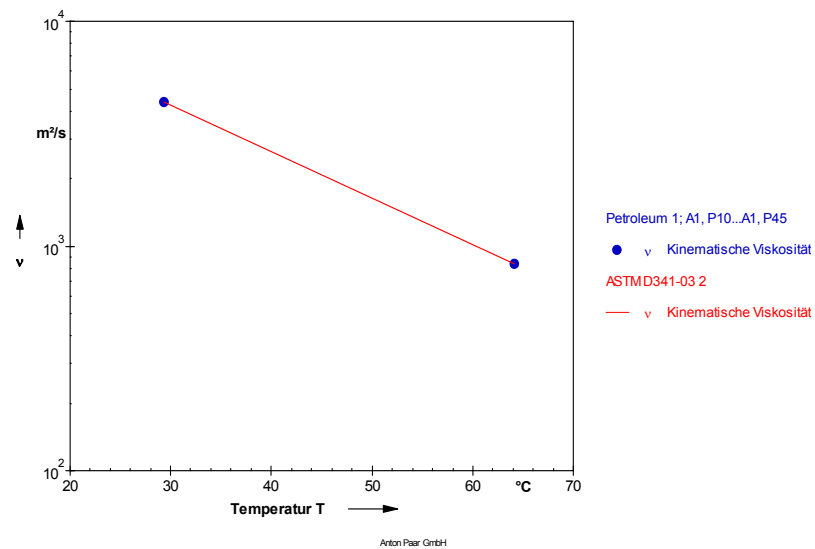


Fig. 5 - 80 Visco-Temp ASTM 341-93 - Example



5.43 Viscosity $d(\tau) / dD$ I

The evaluation method 'Viscosity $d(\tau) / dD$ I' is used to calculate a special viscosity value from the shear rate and shear stress values in the input data. The method for the determination of the viscosity can be selected. As output data points the values x and dy/dx are stored.

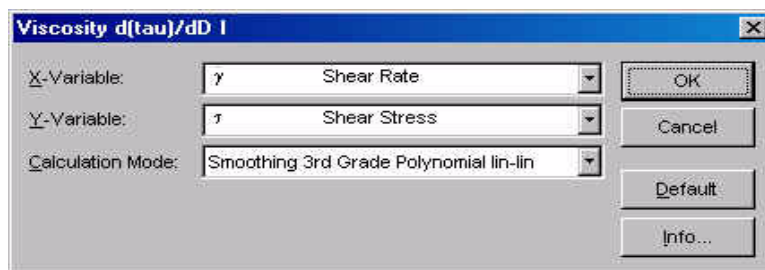


Fig. 5 - 81 Viscosity $d(\tau) / dD$ I - Parameter settings

5.43.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear rate is used as the x-variable, the shear stress is used as the y-variable.

Calculation Mode

Select one of the three calculation methods. With 'Smoothing 3rd Grade Polynomial lin-lin (log-log)' the a 3rd grade polynomial either in linear or in logarithmic scale is used to smooth the input data, then $d(\tau)/dD$ is calculated. With 'Difference Quotient' the viscosity value is calculated by dividing the difference of two adjoining stress values by the difference of the corresponding shear rate values. The equations for all three methods can be found under 'Info' in the parameter dialog box.

5.44 Viscosity Index

This method is used to calculate the viscosity index of petroleum products according to ASTM D 2270-93 (reapproved 1998). The method can use two different procedures (A or B) for calculation. As input data the method requires a data series with two data points which show the sample's kinematic viscosity at about 40 °C and at about 100 °C.

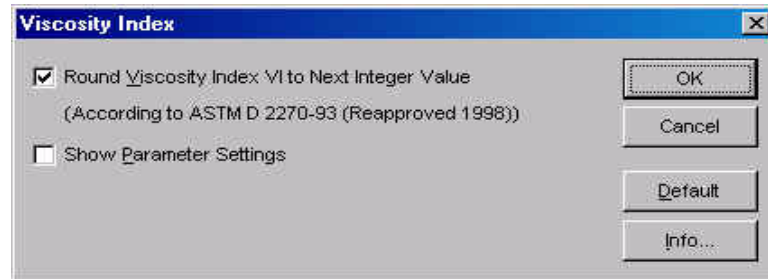


Fig. 5 - 82 Viscosity Index - Parameter settings

5.44.1 Parameters and Default Settings

Round Viscosity Index....

If this option is activated, the calculated value for the viscosity index is rounded to the nearest integer value. The rounding is according to the ASTM standard.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

5.44.2 Output data

The result contains the number of input and output data points, the viscosity values at both temperatures and the viscosity index. Further, the intermediate variables and the calculation procedure are listed.

5.45 Visco-Temp ASTM D 341-03

5.46 Waveform

The method 'Waveform' can be used to either generate single or multiple frequency waves or to analyse the harmonics of a result from oscillatory measurements. It can, for example, be used to get information about whether a data point is still inside the linear viscoelastic range. To work with 'Waveform' the measurement, e.g. amplitude sweep, has to be carried out as a multiwave measurement where the amplitude factor has been set to zero. As frequency factors in the measurement set the harmonics that you wish to see after the analysis.

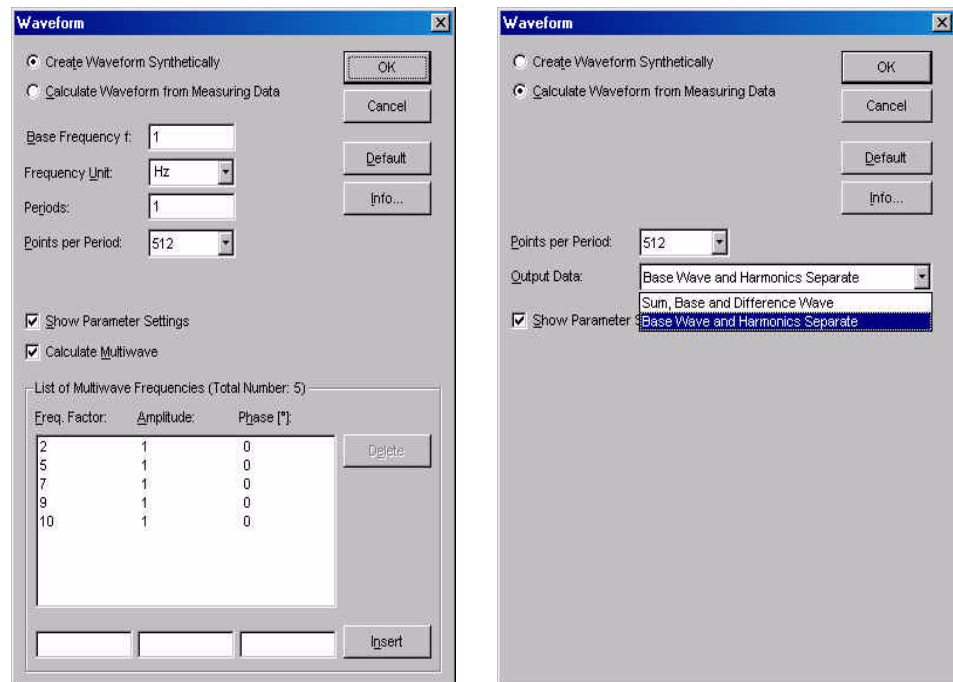


Fig. 5 - 83 Waveform - Parameter settings

5.46.1 Create Waveform Synthetically

Select this option to generate a wave with a single frequency or multiple frequencies. Select the base frequency, the unit, the number of periods you would like to display and the points per period. The default value for the number of points is 512.

To calculate multiwave data enable the option 'Calculate Multiwave' and enter the frequency factor, the factor for the amplitude and the phase shift, if any. Then click 'Insert'.

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Please observe that it is necessary to select an input data series for this option as well. The data from this data series are not used, it can contain any type of measurement.

5.46.2 Calculate Waveform from Measuring Data

Select this option to analyse the result of an oscillatory measurement for harmonics. Choose the number of data points and one of the options for 'Output Data'. The results of both options are shown in the examples below.

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

This option requires on single input data point. To be able to analyse the data point, it needs to be measured with multiwave. For information on setting up a multiwave measurement please see volume 2 of this manual.

5.46.3 Example

The example shows the results of both analysis options for data from a multiwave measurement. The first diagram shows sum, base and difference wave, the second base wave and harmonics.

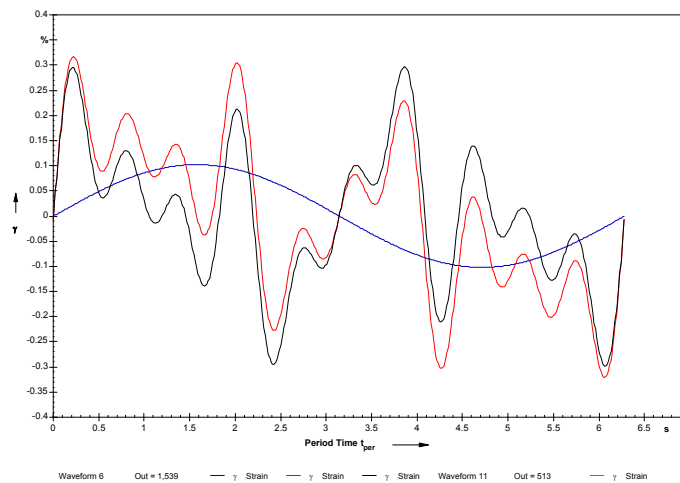


Fig. 5 - 84 Waveform - Example (Sum, Base and Difference Wave)

To present the results from a 'Waveform' analysis create a diagram that shows the period time on the x-axis and the strain on the y-axis; for synthetical waveforms you need to select Y as the variable for the y-axis.

The dialog box for selecting the viewing data contains an option 'Index' which needs to be checked if the result from a waveform analysis is to be presented as separate curves. Enable the option and enter the index range for each curve. The 'Index' option is only shown if 'Intervals' or 'Data Points' has been selected.

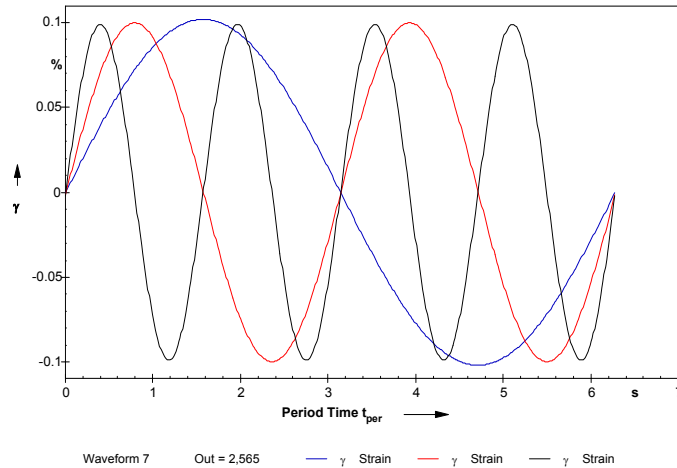


Fig. 5 - 85 Waveform - Example (Base Wave and Harmonics Separate)

The base wave is stored with the index 1, the sum wave has the index 2 and the difference wave has the index 3. For the calculation option 'Base Wave and Harmonics Separate' the index 1 is used for the base wave, the harmonics use the index in increasing order.

5.47 WLF I

The Williams-Landel-Ferry equation describes the temperature dependence of the viscoelastic properties of a material. It is used for the time temperature superposition of viscoelastic data. Measurement data, from a frequency sweep for example, taken at one temperature can be shifted horizontally to complement the data taken at a different temperature. Thus, the material properties can be studied over a broader frequency range than it would be possible with just the measurement data at a limited frequency range.

The constants a and b are typical values for the material that has been measured, they can be calculated with the 'WLF I' evaluation.

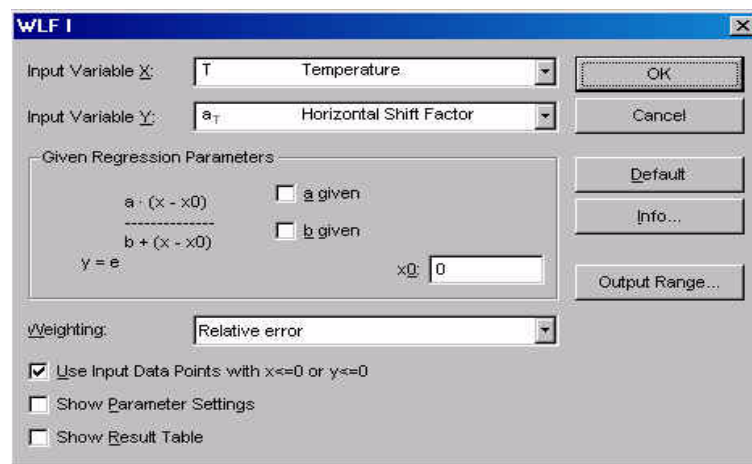


Fig. 5 - 86 WLF I - Parameter settings

$$y = e^{\frac{a \cdot (x - x_0)}{b + (x - x_0)}}$$

- x - input variable x
- y - input variable y
- a - material dependent constant 1
- b - material dependent constant 2
- x₀ - reference value of the x-variable

5.47.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the temperature is used as the x-variable, the shift factor a_T is used as the y-variable.

Regression parameters

The regression parameters are calculated by the evaluation algorithm to fit the calculated to the measured values. If any of the regression parameters is known you can check it in the dialog box and enter the value. The method will then only calculate the remaining parameters.

Weighting

The recommended setting for 'Weighting' is relative error. With this option the difference between calculated and measured values of the y-variable is weighted evenly at small and at large x-values.

If the option 'Absolute error' is used, the differences between calculated and measured values at large x-values are weighted more than those at small x-values. This setting, as well as the third settings 'RS100 / RS120 compatible', should only be used for compatibility purposes. The third setting uses the weighting method from the software RS 100 and RS 120.

Input Data Points with $x \leq 0$ or $y \leq 0$

The option 'Input Data Points with $x \leq 0$ or $y \leq 0$ ' has to be checked if you want the analysis to use negative values of either the x-variable or the y-variable (input data).

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

Show Result Table

If the option 'Show Result Table' is checked, the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

5.47.2 Example

The example shows data for a polystyrene sample. The shift factor can be taken from a horizontal shift of frequency sweeps at different temperatures. The 'WLF I' evaluation has calculated the material constant 'a' as -12.7 and 'b' as 49.85.

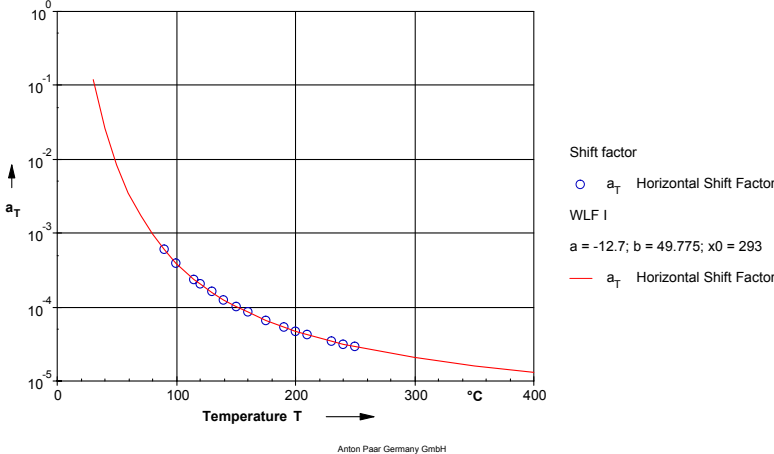


Fig. 5 - 87 WLF I - Example

5.48 Yield Stress I

The method 'Yield Stress I' is used to determine the yield stress of a material using the stress-strain curve from either a rotational or an oscillation test. The yield stress as measured with this type of test is the point where the relationship between strain and stress, i.e. the slope of the strain-stress curve, changes which is taken to indicate a significant change in the structure of the material.

For the calculation of the yield point a regression is done on the parts of the curve below and above the point where the slope changes. The yield point is the point where both regression lines cross each other.

To be able to evaluate the measurement data correctly a sufficient number of data points has to be available below and above the yield point. A high number of measurement points makes the calculation of the yield point more exact. Further, it is recommended to use logarithmic settings for the measurement as the regressions are carried out logarithmically. If the stress-straincurve (see also example) shows a downward bend at the lowest stress values these points should not be used for the evaluation as this may result in incorrect data.

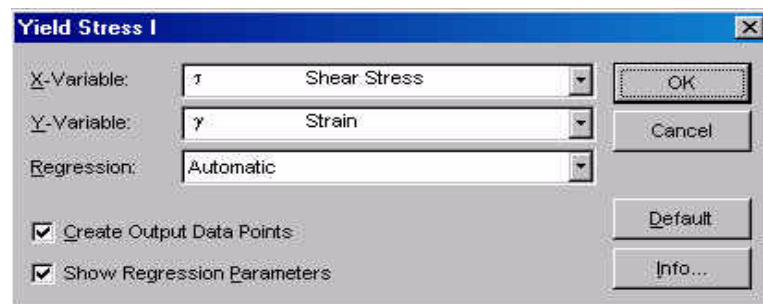


Fig. 5 - 88 Yield Stress I - Parameter settings

5.48.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear stress is used as the x-variable, the strain is used as the y-variable.

Show Regression Parameter

If the option 'Show Regression Parameters' is checked the result field in the analysis window will include the parameters for the regression that has been done on the upper and lower part of the curve.

5.48.2 Regression

There are three options available: 'Automatic', 'Linear/Linear' and 'Linear / Polynomial 3. order'.

- 'Linear/Linear'
A linear regression is done on both parts of the curve.
- 'Linear / Polynomial 3rd order'
With 'Linear / Polynomial 3rd order' a linear regression is done on that part of the curve that is below the yield point and a third order polynomial is fitted to the curve above the yield point.
- 'Automatic'
If 'Automatic' is selected the software does both regression types and selects the type that fits the measurement data best for the calculation of the yield point.

5.48.3 Example

The example shows the stress-strain curves of two handcreme samples in a logarithmic diagram. It can be seen that both curves have a constant slope up to a certain stress (or stress range). There, the slope suddenly changes significantly to a different value. The symbols show the measurement data, the lines are the regression curves as calculated by the 'Yield stress I' method. The yield stress values are given in the legend of the diagram and the heading of the data table.

The measurement data in this example were taken from an amplitude sweep.

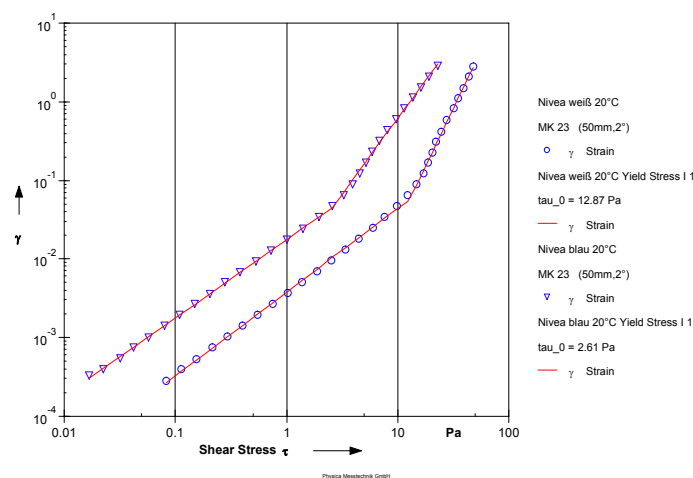


Fig. 5 - 89 Yield stress I - Example

5.49 Yield Stress II

The 'Yield Stress II' determines the yield stress of a material by calculating the bending point in a stress-strain curve in a logarithmic plot. The evaluation does a regression on the input data and checks for the point with the largest distance to the regression line. This point is taken as the yield point. As for the 'Yield Stress I' method it is recommended to use logarithmic settings and a sufficient number of data points.

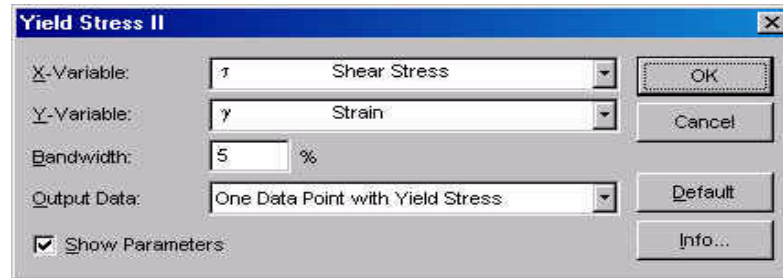


Fig. 5 - 90 Yield Stress II - Parameter settings

5.49.1 Parameters and Default Settings

Input Variable X / Input Variable Y

Select the 'Input Variable X' and the 'Input Variable Y' from the list. The x-variable is the independent variable, the y-variable is a function of x (dependent variable). As a default the shear stress is used as the x-variable, the strain is used as the y-variable.

Bandwidth

The bandwidth is used to estimate the lower and upper boundary for the error of the calculated yield stress value. The bandwidth value is given in %.

Show Parameters

If the option 'Show Parameters' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

5.49.2 Output data

As output data, usually the option 'One Data Point with Yield Stress' is selected. This option displays the yield stress value as a single data point in table and diagram.

The option 'Curve with Calculation Criterion' stores the calculated difference between measured data and regression line in the output data series. The calculation criterion is stored as the variable 'Y' and can be displayed in table and diagram. The curve shape can be used to determine how distinct the bend in the stress-strain curve is.

If the option 'No Output Data' is selected the analysis result will not contain any data points. The yield stress value will be shown in the result field.

5.49.3 Example

The upper diagram in the example shows the measured stress-strain curves of two handcreme samples and the calculated yield stress as single data points. The lower diagram shows the calculation criterion for both samples; the yield stress is the point where the Y-value, i.e. the distance between measured data and regression line, reaches the maximum.

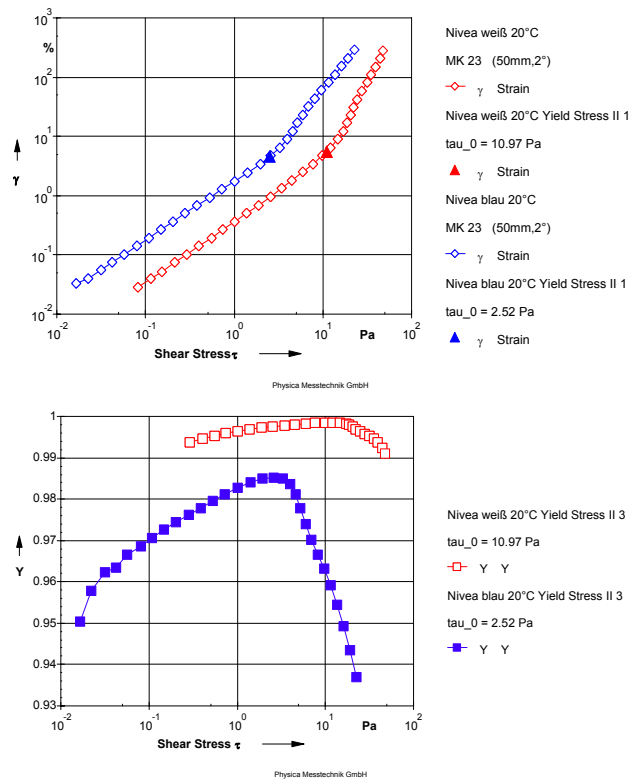


Fig. 5 - 91 Yield Stress II - Example

6 Basic Analysis

The evaluation methods of the group 'Basic Analysis' allow a number of operations on the data of the input data series. For example, a mean value can be built of the values within a data series or of several data series. Mathematical operations can be carried out on the values and data series can be linked through mathematical operations, e.g. the values of two data series can be added. It is also possible to merge data series or separate e.g. multiwave data into data series with a single frequency. A sorting of values within a data series can also be carried out.

6.1 Basic Arithmetic Operations

This method can be used to carry out arithmetic operations on one or all variables of the input data series. The available operations are addition, multiplication, absolute value, natural logarithm, exponential function, base 10 logarithm, square root and power function. With this method it is possible to correct the values of the selected variable (or all variables). An example is the correction of a time offset in a time-dependent measurement.



It is possible to store the changed data as a new variable. Note that it may have severe consequences on your data if any of the default variables are selected as the new output variable. You are using this option at your own responsibility. It is recommended to define a variable that is used only for this purpose.

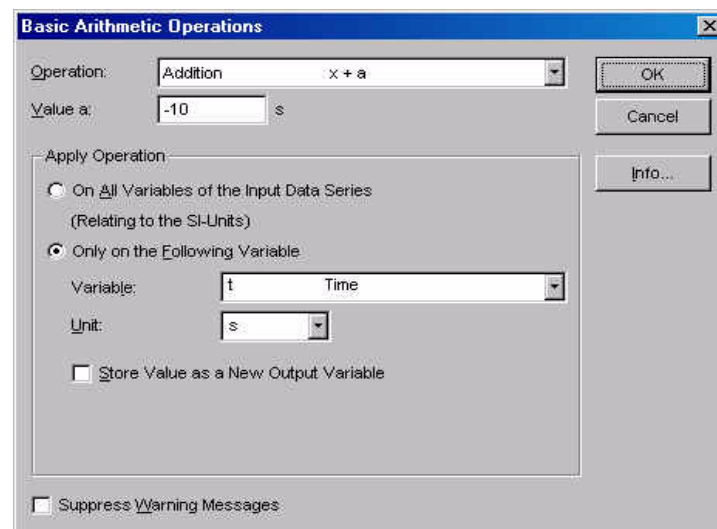


Fig. 6 - 1 Basic Arithmetic Operations - Parameter settings

6.1.1 Parameter Settings

Operation

Select the operation you would like to use from the list.

Value a

A value 'a' needs to be entered for the operations addition, multiplication, division and power function.

Apply Operation On All Variables of the Input Data Series

If this option is selected the operation will be carried out on all input variables, all values will be changed. This operation will use the values in SI units for the calculation.

Apply Operation Only on the Following Variable

If this option is selected the operation will be carried out on the selected variable. The unit of the variable can be selected.

Store Value as a New Output Value

With this option the changed value of the selected variable will be stored under a different name. As this may have severe consequences on the data it is recommended to use this option with great care. Only variables that have been defined for this purpose should be used. Please note that you are using this option at your own responsibility.

6.2 ER-Analysis

This analysis method is used to generate data for the relative permeability, the field strength and flux density. These data, as well as the electric current, are added to the input data series. With these data it becomes possible to display the measured values as a function of e.g. the magnetic flux density B directly in the Rheoplus software.

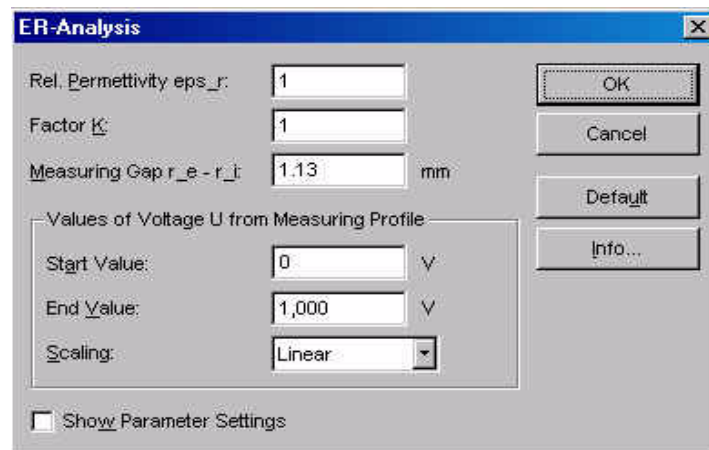


Fig. 6 - 2 ER-Analysis - Parameter settings

6.2.1 Parameter Settings

Rel. Permittivity eps_r

The permittivity gives a measure of the permittivity of a material for an electric field. Enter the relative permittivity of the sample under analysis.

Factor K

The factor K can be used to calibrate the values of the magnetic flux density B . By default, this value is set to 1.

Gap

Geben Sie hier den Messspalt des verwendeten Messsystems (Becherradius - Messzylinderradius) an.

Values of Voltage U from Measuring Profile

The voltage values that are used during the measurement are not stored with the measurement results. Enter the start and end value as given in the measuring profile. Further, use the same scaling as in the measuring profile.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

6.2.2 Example

The example shows an oscillation time sweep on a magnetorheological fluid. During the measurement, the current has been increased from 0.001 A to 2 A as shown in the figure to the right. This figure shows both the rheological values (G' , G'') and the current as a function of the measurement time. In the figure to the left, the dependence of the storage and loss modulus on the magnetic flux density is shown.

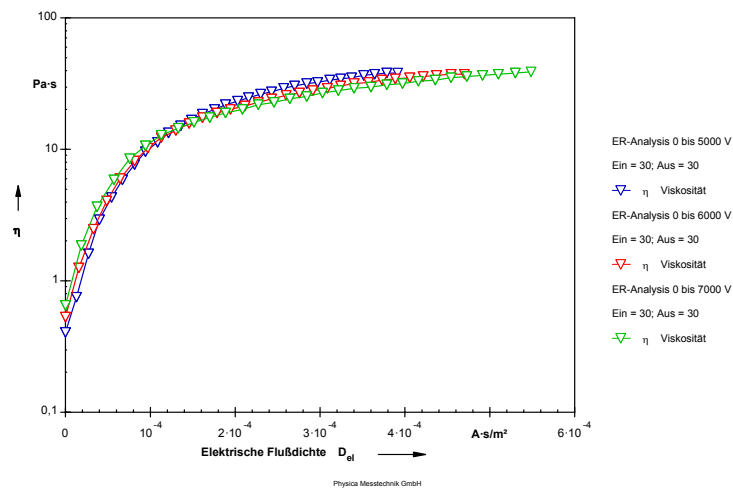


Fig. 6 - 3 ER-Analysis - Example

6.3 Interpolation (Fill Points)

The method 'Interpolation (Fill Points)' generates the selected number of data points between two points of the input data series. These points can be selected by the user. The interpolated data points can be distributed linear or logarithmically. The interpolation is done on all variables in the input curve.

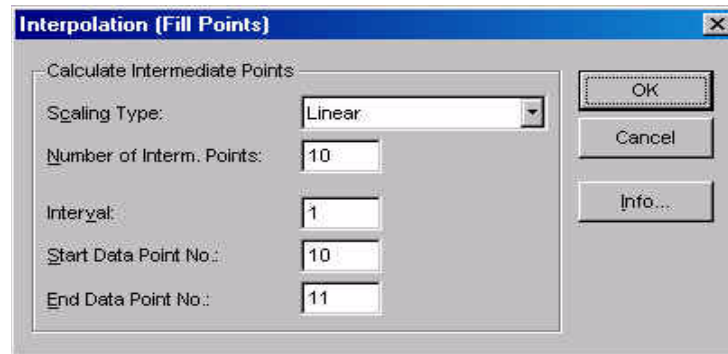


Fig. 6 - 4 Interpolation (Fill Points) - Parameter settings

6.3.1 Parameter Settings

Scaling Type

The scaling type decides whether the generated data points are distributed linear or logarithmically. Select the required scaling type from the list.

Number of Interm.(ediate) Points

Enter the number of points that should be generated between the two data points of the input data series.

Interval / Start Data Point No. / End Data Point No

These values define the two data points in between the new data points should be generated. The interval is the measurement interval that contains these two data points. Please note that only the complete data series can be used as input data, not single intervals.

6.4 Interpolation (Single Point)

The method 'Interpolation (Single Point)' allows to interpolate between several data points or to create a data series with evenly distributed data points from an input data series that has e.g. not evenly distributed x-values. The parameter settings of this method are different from the 'Interpolation (Fill Point)' method in that that here the x-values of the data points that are to be interpolated are entered by the user respectively read from a second input data series. It is possible to enter a range of x-values and the number of required data points in between.

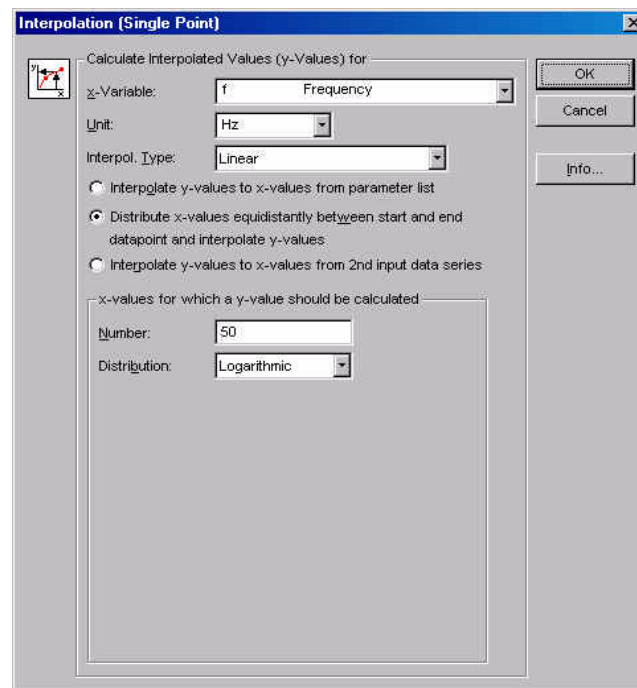


Fig. 6 - 5 Interpolation (Single Point) - Parameter settings

6.4.1 Parameter Settings

'x-Variable' and 'Unit'

Select the x-variable and the unit from the list. Make sure to select the same unit you are using for the data you are entering as x-values. The x-variable has to be available in the input data.

Interpolation

The available interpolation types are linear, logarithmic and cubic spline. The equations for the calculation of the interpolated values can be found under 'Info' in the parameter window of this analysis method.

6.4.2 Interpolate y-values to single x-values

With this option y-values are calculated for the x-values that have been entered in the list. These x-values can either be added one by one or generated automatically.

To add x-values enter them in the text box 'x-Value' and click 'Add'.

To generate x-values automatically enter start and end value and the number of required x-values. Then click 'Add'. The calculated x-values will be shown in the list. The calculated x-values can be distributed linear or logarithmic.

Fig. 6 - 6 Interpolation (Single Point) - Parameter settings

6.4.3 Distribute x-values equidistantly between start and end datapoint and interpolate y-values

With this option the software uses the first and the last data point of the input data as start and end value for the calculation of the x-values. Enter the number of required x-values and the distribution, linear or logarithmic. The example below shows the measurement data with linear distribution of the data points and the calculated curve with logarithmic distribution.

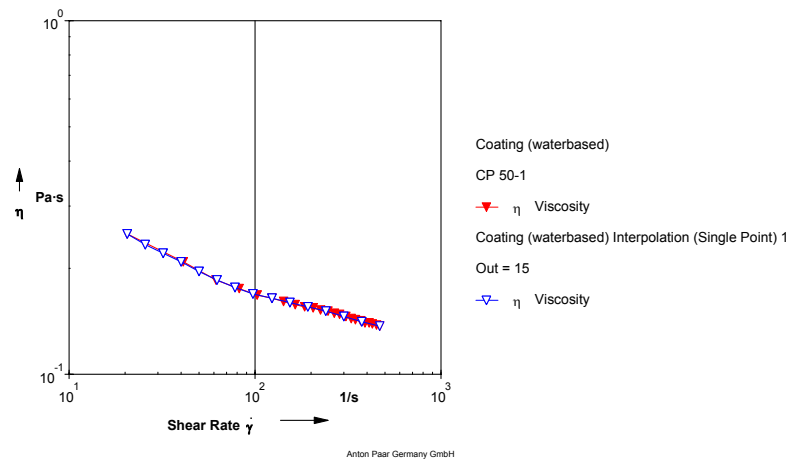


Fig. 6 - 7 Interpolation (Single Point) - Example

6.4.4 Interpolate y-values to x-values from 2nd input data series

If this option is selected, the x-values for the interpolation are taken from a second input data series. The y-values of the first input data series are interpolated. Make sure you select both input data series and in the correct order.

6.5 Link Data Series

The method 'Link Data Series' allows basic arithmetic operations on a selected variable between two data series. The values of the selected variable are e.g. added while the other values remain unchanged. The result data series contains the variable on which the operation has been carried out and the variables of the first input data series. The variables of the second input data series are not used, except the selected one.

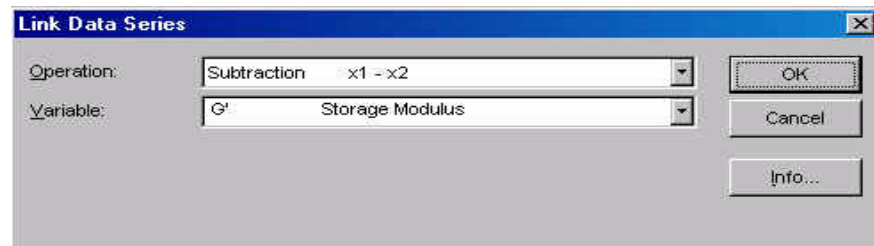


Fig. 6 - 8 Link Data Series - Parameter settings

6.5.1 Settings

Operation

Select the operation you would like to use from the list.

Variable

Select the variable on which the operation should be carried out from the list. Please note that the variable has to be available in both input data series.

6.5.2 Example

In the example 'Link Data Series' has been used to calculate the difference between the measured data in a temperature sweep and a reference curve. The settings are as shown in figure Fig. 6 - 8.

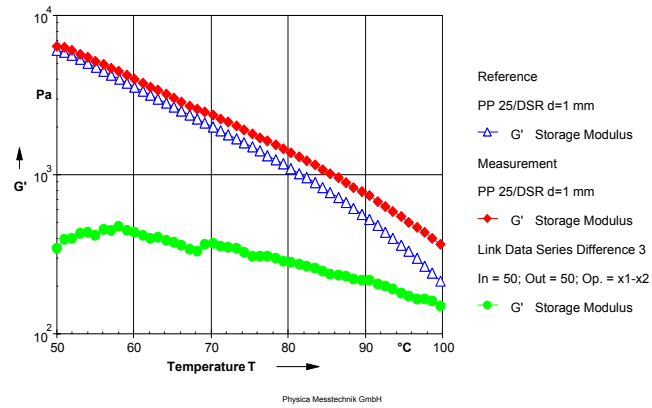


Fig. 6 - 9 Link Data Series - Example

6.6 Mean Value 'In'

The method 'Mean Value In' calculates the average of the data points within one input data series. All variables of the selected input data series are included in the calculation. This method can e.g. be used to calculate the average of values that vary around a medium value to achieve the average of several data points.

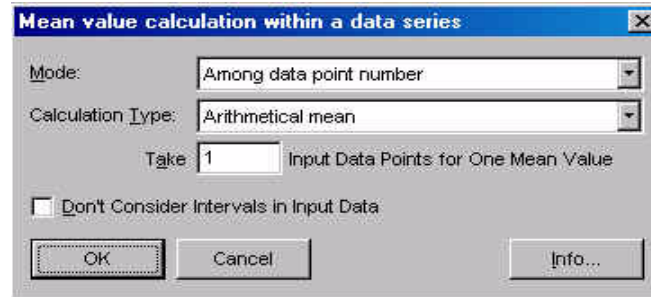


Fig. 6 - 10 Mean value 'In' - Parameter settings

6.6.1 Mode

The default setting is to use all data points in an interval, i.e. all valid data points from the data series defined as input data.

If the option 'Among incoming data points' is used, the calculation of the mean value is based on the number of data points given in 'Count', starting from the first data point in the input data series or interval. Invalid or disabled data points are not used; if such a point is found the analysis will continue with the following point until the defined number is reached.

With the option 'Among data point number' the value for 'Count' is decreased if invalid or disabled data points are found in the defined input data series. In case the value 'Count' reaches zero, no result data point is calculated.

6.6.2 Calculation type

With 'Arithmetical mean' the following equation is used:

$$x_{mean} = \frac{1}{n} \cdot \sum_{i=1}^n x_i$$

With 'Root mean square' the following equation is used:

$$x_{mean} = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^n x_i \cdot x_i}$$

n - number of data points used for calculating the mean value

6.6.3 Example

In this example the method 'Mean value In' has been used to calculate the average value in the Newtonian region of the sample to get a value for the zero shear viscosity of the material. As input data the interval from the first data point to the onset of the shear thinning behaviour has been used.

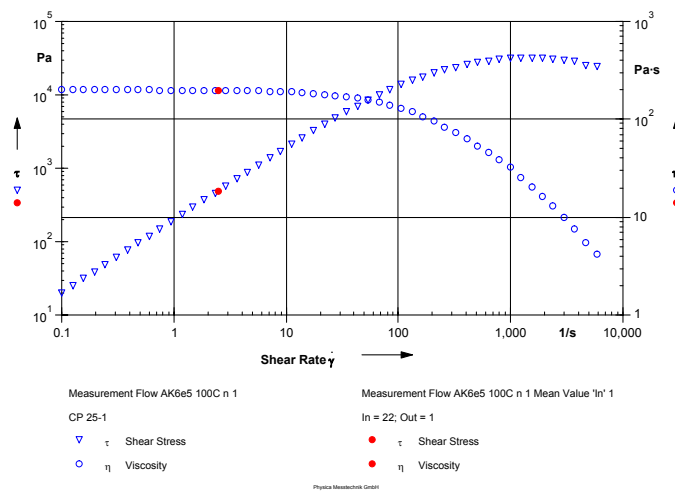


Fig. 6 - 11 Mean Value In - Example

6.7 Mean Value 'Out'

With 'Mean Value Out' the average of several input data series can be calculated for each input data point. This is e.g. useful to calculate one value from a double testing of a material. In this method all variables are used for the calculation and stored in the output data series.

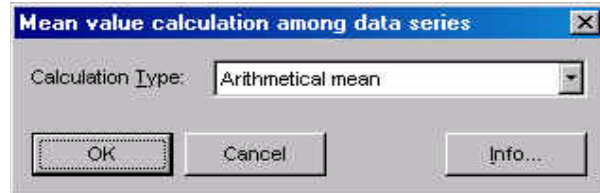


Fig. 6 - 12 Mean Value 'Out' - Parameter settings

6.7.1 Settings

Select the calculation type.

With 'Arithmetical mean' the following equation is used:

$$x_{mean} = \frac{1}{n} \cdot \sum_{i=1}^n x_i$$

With 'Root mean square' the following equation is used:

$$x_{mean} = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^n x_i \cdot x_i}$$

n - number of data points used for calculating the mean value

6.7.2 Example

The example shows two flow curve measurements on a high viscous oil and the calculated mean value curves.

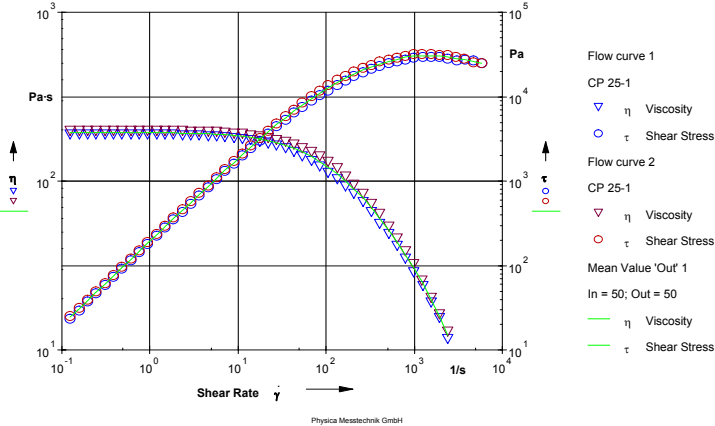


Fig. 6 - 13 Mean Value 'Out' - Example

6.8 MergeToMulti

The method 'MergeToMulti' can be used to create two-dimensional data series from a number of one-dimensional data series. As an example, frequency sweeps at several temperatures can be merged to a multiwave temperature sweep, or two curves, representing the upper and lower limit of the required curve for quality control purposes, can be merged into a single data series.

The data series that are to be merged need to have the same variables and an identical number of data points. The merging is carried out point-by-point on all input data series, i.e. the first data points of all input data is merged into the first output data point, the second points into the second output data point and so on.

6.8.1 Settings

There are no parameter settings available for this method.

6.8.2 Example

In this example 'MergeToMulti' has been used to merge frequency sweep measurements carried out at three different temperatures into a multiwave sweep. The sample has been a polymer.

The first figure below shows the three single frequency sweeps, at 180 °C, 200 °C and 230 °C.

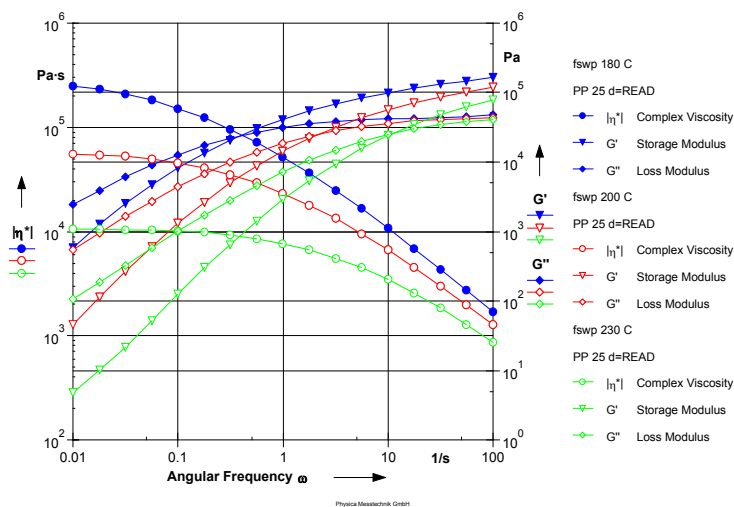


Fig. 6 - 14 'MergeToMulti' - Example (input data series)

The second figure shows the complex viscosity of the input data series as single curves (symbols and projection lines) and the multiwave data as plane in a three dimensional diagram. The three dimensional diagram shows the viscosity as a function of both frequency and temperature.

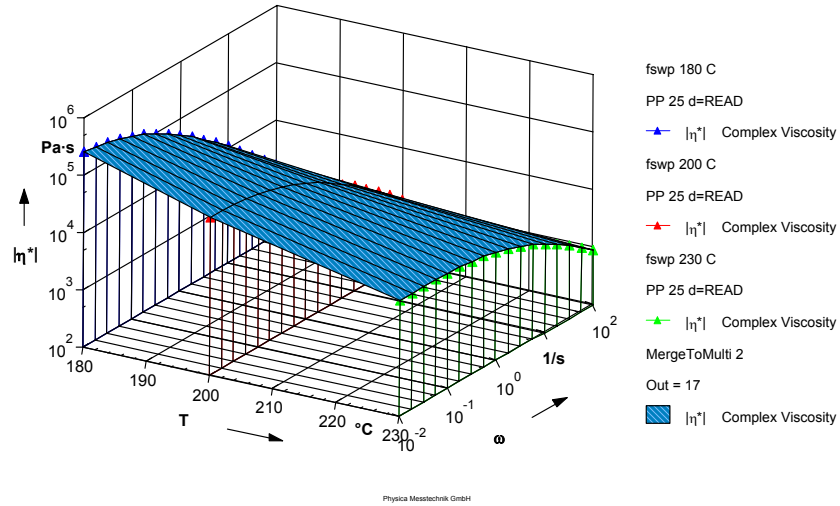


Fig. 6 - 15 'MergeToMulti' - Example (result)

6.9 Merging

The method 'Merging' allows to combine several input data series to a single result data series. The input data series need to have the same variables.



Fig. 6 - 16 Merging - Parameter settings

6.9.1 Parameter Settings

By default, the input data series are stored into one interval in the analysis result. If the option 'Store Each Input Data Series...' is checked, the result contains the input data in single intervals.

Check the option 'Consider Absolute Time' to change the time of the output data to the value of the absolute time in the input data.

6.10 Min-Max-Limits

The method 'Min-Max-Limits' allows to remove certain points from a data series based on the value of one variable. This variable can be selected by the user. With this method unwanted points can be removed from the input data series or it can be used to divide a measurement result containing data from several constant temperatures into single data series.

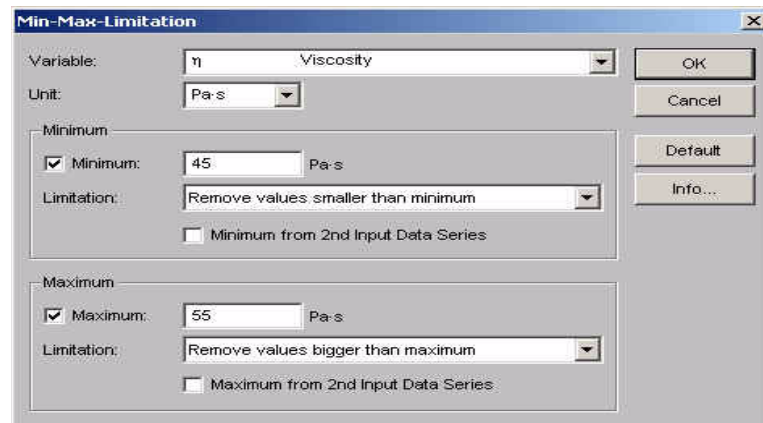


Fig. 6 - 17 *Min-Max-Limitation - Parameter settings*

6.10.1 Settings

Variable / Unit

Select the variable whose values should be used as a criterion and the unit.

Minimum

If you would like to remove values below a certain value check the option 'Minimum' and enter the value. The default setting for the limitation is to remove values that are smaller than the set value, as an alternative the data points below the limit value can be set to that value.

Maximum

If you would like to remove values above a certain value check the option 'Maximum' and enter the value. The default setting for the limitation is to remove values that are above the set value, as an alternative the data points above the limit value can be set to that value.

It is possible to enable both 'Maximum' and 'Minimum' at the same time. The values that are equal to the limit value are always included in the result data series.

Minimum / Maximum from 2nd Input Data Series

Enable this option to use the value from a second data series as the minimum or maximum.

6.11 MR-Analysis

This analysis method is used to generate data for the relative permeability, the field strength and flux density. These data, as well as the electric current, are added to the input data series. With these data it becomes possible to display the measured values as a function of e.g. the magnetic flux density B directly in the Rheoplus software.

The screenshot shows the 'MR-Analysis' dialog box with two main sections for parameter settings.

Dependency Rel. Permeability of Sample $\mu_r=f(H)$:

Field St. H [A/m]	Rel. Perm. μ_r [1]
1,715	1
2,059	1.049
2,471	1.1
2,967	1.154
3,561	1.211

Buttons: Add, Delete, Paste from Clipboard

Dependency Magn. Flux Density without Sample $B=f(I)$:

Current I [A]	Flux Dens. B [T]

Buttons: Add, Delete, Paste from Clipboard

If not in Input Data:

Gap: 1 mm

Current I [A]: Start Value: 0.1, End Value: 2

Scaling: Linear

Show Parameter Settings

Fig. 6 - 18 MR-Analysis - Parameter settings

6.11.1 Parameter Settings

Factor K

The factor K can be used to calibrate the values of the magnetic flux density B . By default, this value is set to 1.

Gap

If the measuring gap is not available in the input data, enter the value here.

Values of Current I

The set values of the current I that are used in the measurement are not stored with the measurement data. Enter the start and end value for the electric current as they have been entered in the measurement profile. Also, select the scaling type as in the measurement.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

6.11.2 List with Relative Permeability $\mu_r = f(H)$

In this list you can enter, import or generate the data for the relative permeability μ_r of the sample as a function of the magnetic field strength H . The value(s) for μ_r are used to calculate the magnetic flux density according to the equation below:

$$B = \frac{7,539 \cdot 10^{-4} \cdot K \cdot I}{(0,0035 - d) \cdot \left(\frac{\mu_r - 1}{\mu_r}\right)}$$

B - magnetic flux density
K - calibration factor
I - electric current
d - measuring gap
 μ_r - relative permeability

As the values are dependent on each other, see equation below, the calculation is done by iteration. The calculation stops after a maximum of 10000 iterations or if the relative deviation of the relative permeability between the current and the last iteration is below 10^{-6} .

$$H = \frac{B}{\mu_0 - \mu_r}$$

H - magnetic field strength

with:

$$\mu_0 = 1,256 \cdot 10^{-6} \frac{Vs}{Am}$$

To enter the values for H and μ_r manually enter each pair of values in the respective text box and click 'Add'. The values will be shown in the list. To carry out the analysis with μ_r independent of H enter just one value for each variable.

To import the data from another application, e.g. Excel, copy the data in that application and click 'Paste from Clipboard'.

To generate the data enter start and end value for both H and μ_r , the number of values in between ('Count') and select the scaling type; then click 'Add'. The software will automatically generate the data for the list.

6.11.3 Example

The example shows an oscillation time sweep on a magnetorheological fluid. During the measurement, the current has been increased from 0.001 A to 2 A as shown in the figure to the right. This figure shows both the rheological values (G' , G'') and the current as a function of the measurement time. In the figure to the left, the dependence of the storage and loss modulus on the magnetic flux density is shown.

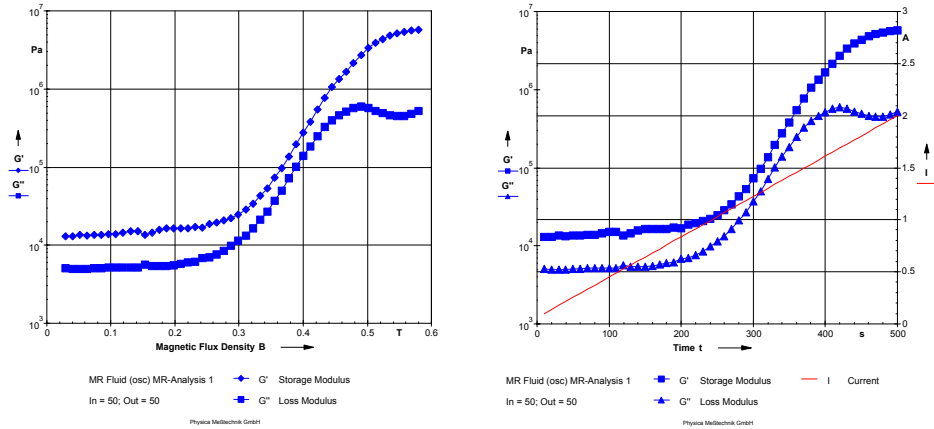


Fig. 6 - 19 MR-Analysis - Example

6.12 MultiToSingle

The method 'MultiToSingle' is used to generate one-dimensional data from two-dimensional measurement data, e.g. single frequency curves from a multiwave measurement. You can select whether the result should contain all components, i.e. all upper wave for multiwave data, or a defined range of components.

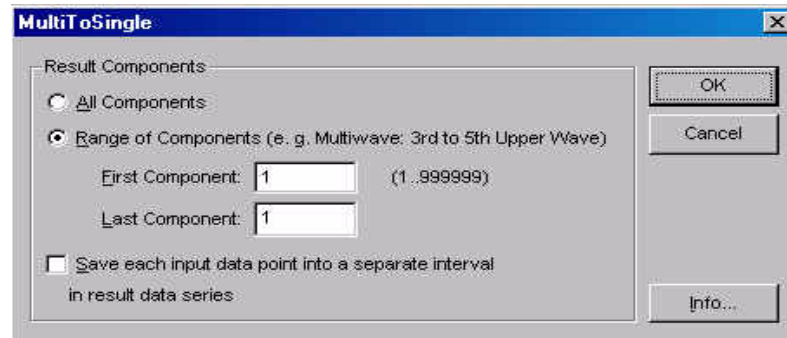


Fig. 6 - 20 MultiToSingle - Parameter settings

6.12.1 Settings

All Components / Range of Components

Select the required option. If the option 'Range of Components' has been selected, you also need to enter the start and end value of the range.

Save each input data point into a separate interval in result data series

If this option is checked the analysis result will be divided in intervals, e.g. the data from a multiwave temperature sweep will contain frequency sweep data at each measured temperature.

6.12.2 Example

The example shows a multiwave temperature sweep on a polymer which has been carried out at 0.1 1/s and upper frequencies of 2, 4, 7 and 10 times the base frequency. The multiwave data are shown in the three dimensional diagram.

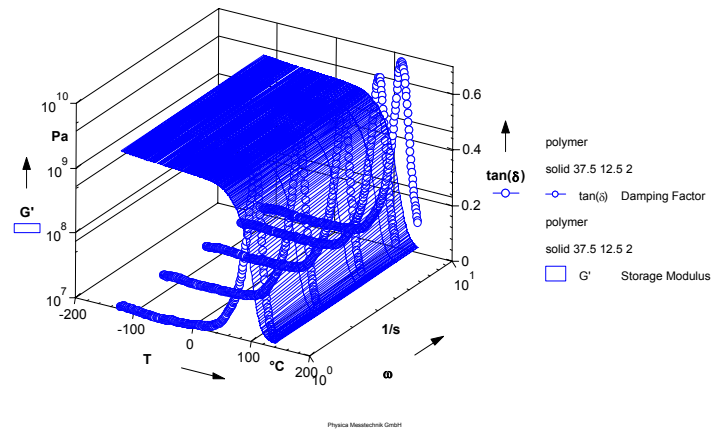


Fig. 6 - 21 'MultiToSingle' - Example (input data)

The two dimensional diagram shows the temperature sweeps for two of the frequencies that were contained in the multiwave spectrum. The data have been smoothed (using the method 'Smoothing'). The differences in the location of the transition points can be seen clearly.

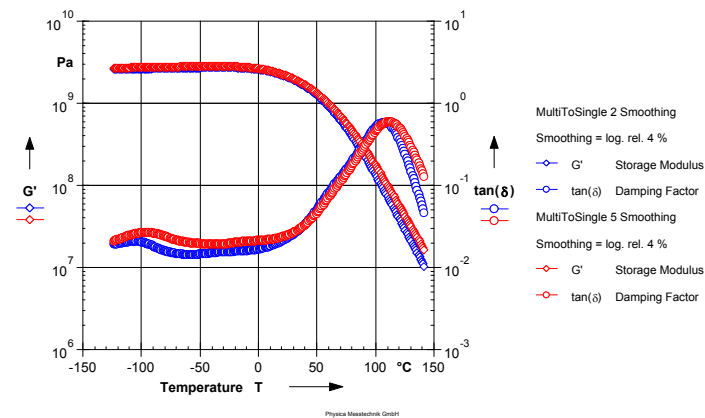


Fig. 6 - 22 'MultiToSingle' - Example (output data)

6.13 Select Points

The method 'Select Points' can be used to reduce the number of data points in a data series. Every xth data point is used.

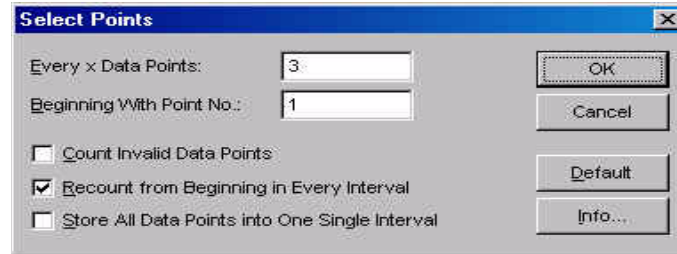


Fig. 6 - 23 MultiToSingle - Parameter settings

6.13.1 Settings

Every x Data Points

Enter the value for x. Every x data point from the input data series is stored in the output data series.

Beginning With Point No.:

The counting and deleting of the data points starts with the data point whose number is entered in this field.

Count Invalid Data Points

If this option is enabled the method will count invalid data points as well, these are discarded by default.

Recount from Beginning in Every Interval

The data point numbers of the output data series start with point 1 for each interval if this option is enabled. If this option is disabled the data points will receive consecutive numbers, independent of whether they are in one or in several intervals.

Store All Data Points into One Single Interval

Enable this option to remove all intervals from the input data series. The output data series will only contain one interval.

6.14 Sorting

The method 'Sorting' can be used to sort the data points in an interval or data series in the order of the actual values of the selected variable. This can for example be used to sort the measurement data of a stress sweep (rotational mode) for the determination of the yield stress.

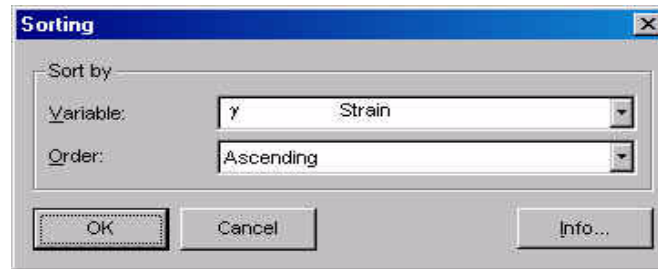


Fig. 6 - 24 Sorting - Parameter settings

6.14.1 Settings

Variable

Select the variable on which the sorting should be based.

Order

Select whether the values in the result data series should be sorted ascending or descending (referring to the selected variable).

7 QC - Quality Control

7.1 'Quality Control'

The quality control evaluation is a very flexible method to compare measured data to previously defined required values including a user defined tolerance band. It is e.g. possible to store a 'master curve' and an allowable tolerance with this analysis method and compare the input data to this curve.

The type and amount of output data for the output data series can be defined as well. Besides the content of the output data series a result text can be defined that contains free text and the analysis results as macros. This result text is shown in the result window of the analysis window and can be printed out.

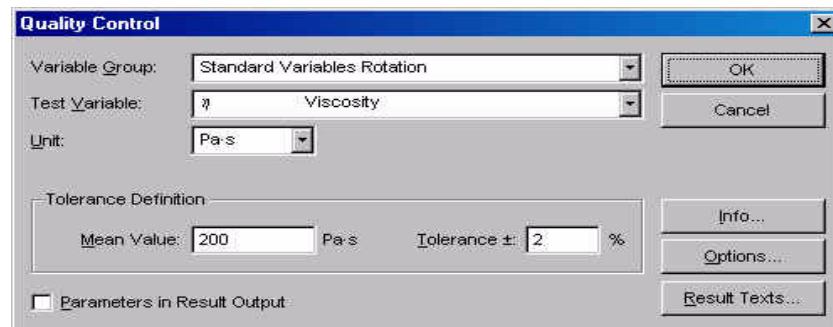


Fig. 7 - 1 Quality Control - Parameter settings

7.1.1 Setting up the quality control module - Overview

1. Select the test variable and its unit from the relevant list in the 'Quality Control' dialog.
2. Choose one of the tolerance definitions under 'Options...' unless you wish to use the default method.
3. Enter the required parameters for the selected tolerance definition. These can be the mean value or mean value curve, the upper and lower limit or tolerance in %. The settings for the default method are made in the 'Quality Control' dialog, the settings for the other methods are made under 'Options...'.
4. In the 'Options' dialog define under which conditions the input data series will pass by selecting one of the options from the list 'Passed, if'.

5. In the 'Options' dialog define which data, if any, should be included in the output data series. Close the 'Options' dialog with 'OK'.
6. Define the settings for the result text that will be shown in the result field of the analysis window under 'Result Texts...'

7.1.2 Test variable

Select the variable which should be checked by the 'Quality control' method from the list. Further, select the unit for the test variable unless you wish to use the default variable. By default, the unit defined as default unit will be selected.

The 'Quality control' method can only check for one variable.

7.1.3 Tolerance Definitions

The quality control module includes four different options to define the tolerance, i.e. the mean value and limit values against which the measurement data are to be checked.

- 'Constant relative tolerance with mean value and tolerance value'
This is the default method and it can be set up directly in the 'Quality Control' dialog. Enter the required mean value and the allowable deviation in %. The other tolerance definitions can be set up under 'Options'.
- 'Constant absolute tolerance with lower and upper boundary'
With this tolerance type the upper and lower limit of the tolerance are constant values. Enter the upper and the lower limit for the check variable. The unit is the one selected in the 'Quality control' dialog.
- 'Relative tolerance range with mean value curve and tolerance value'
This tolerance type allows to enter a mean value curve and define a deviation from the mean value in percent as upper and lower limit. The value for the tolerance is entered in the text box 'Tolerance \pm '.
To enter the mean value curve select the x-variable from the list in the 'Options' dialog and either enter the data points manually or import a curve from the clipboard. If the data are entered manually, you need to enter x- and y-value for each data point, then click 'Add'. It is also possible to import a mean value curve from another application, e.g. Microsoft Excel. To do this copy the curve from the application and use the 'Paste from Clipboard' button. The imported values will be shown in the list.

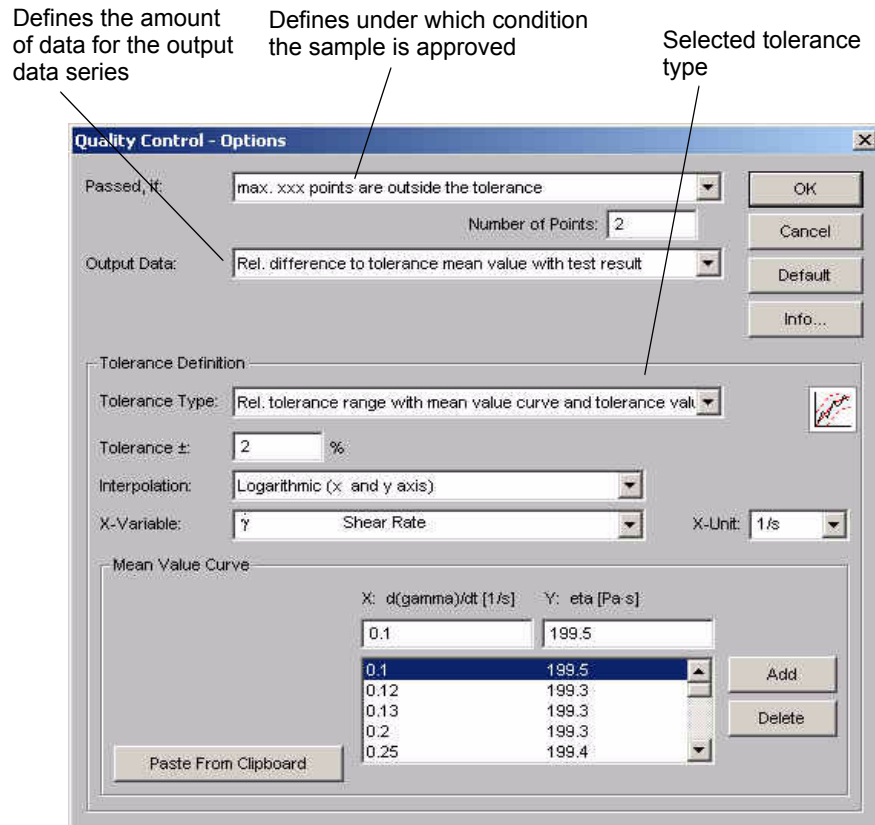


Fig. 7 - 2 Quality Control - Options

- 'Absolute tolerance range with lower and upper boundary curve'
 With this tolerance type the upper and lower limit are entered as absolute values. Up to two curves can be entered. The x-variable has to be the same for both curves; it can be selected from the list.
 To enter the lower limit curve select the option 'Lower Boundary' and enter the x- and y-value for each point, then click 'Add' for each point. When you have finished with the lower limit, select the option 'Upper Boundary' and enter the values for the upper limit curve. To import a curve for the lower or upper limits from another application, e.g. Microsoft Excel, copy the curve from the application and use the 'Paste from Clipboard' button. The imported values will be shown in the list.

The interpolation is used if the datapoints from the input data series do not have the same values as the comparison curve (mean data curve or upper/lower boundary curve). Select the interpolation method or set it to automatic to let the software choose the best fit.

7.1.4 'Passed' criteria

The criterion whether the sample will pass or fail can be selected from the list 'Passed, if'. There are three options available:

- The sample has passed if all input data points are within the tolerance range as defined in the tolerance type.
- The sample has passed if not more than x data points are outside the defined tolerance range. The number of data points can be defined by the user.
- The sample has passed if not more than x% of the input data points are outside the defined tolerance range. The percentage can be defined by the user.

7.1.5 Output data

The selected option under 'Output data' determines which information the output data series will include. The result of the 'Quality Control' evaluation (passed / failed) is always stored with the data series information; it can be found in the text box 'Analysis Result'. The content of the data series can be selected from the 'Output data' list.

- No data point
The output data series does not contain any data points. It will be stored in the datapool.
- One data point with test result
The output data series contains a logical value for the test result, 0 for failed or 1 for passed. To present the data point, the variable 'Logical Value' has to be selected in the table or diagram.
- All input data points with test result
The output data series contains all data points of the input data series. The logical value 1 or 0 can be displayed. The logical value is 1 if the input data series passes the test, it is 0 if the input data series fails the test.
- All points inside the tolerance with test result
The output data series contains only those data points that do not exceed the defined tolerance limits. The test result is stored as a logical value which is 1 if the input data series passes the test and 0 if the input data series fails the test.

- All points outside the tolerance with test result
The output data series contains only those data points that exceed the defined tolerance limits. The test result is stored as a logical value which is 1 if the input data series passes the test and 0 if the input data series fails the test.
- Tolerance boundaries
The output data series contains the limit values that have been defined for the tolerance type.
- Relative difference to tolerance mean value with test result
The output data series contains the deviation of the input data points to the mean value and the test result (passed or failed). The deviation can be displayed by selecting the variable 'Relative Deviation', the test result is stored as a logical value which is 1 if the input data series passes the test and 0 if the input data series fails the test.

7.1.6 Result Texts

The result texts define which information will be displayed in the result box of the analysis window. They can contain both predefined macros which can be selected from a list and user-defined text. Further, the text that is shown in the box 'Analysis Result' in the data series information can be defined in this dialog; see text boxes 'Passed' and 'Failed' at the lower end of the dialog box.

The result text consists of three sections: the header, the data point text and the text for the total result. To use any of these sections for the result they need to be activated in the 'Result Texts' dialog (see checkmark for 'Output Text' in each section).

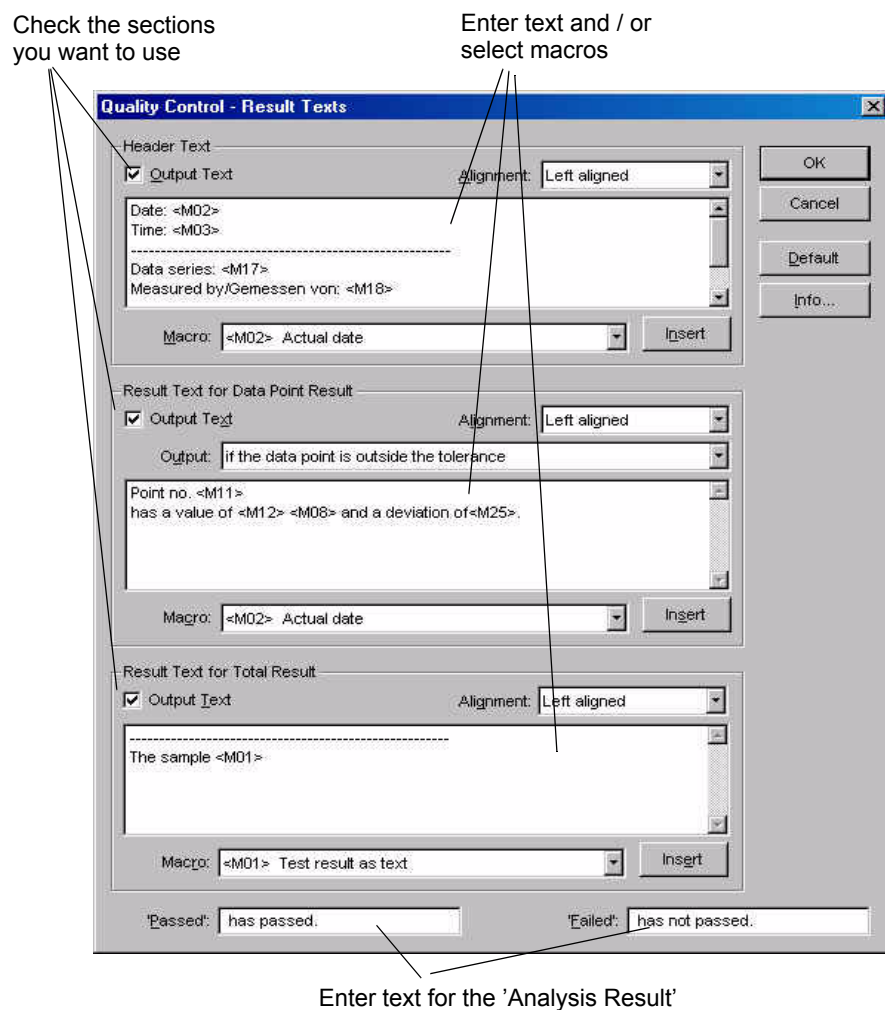


Fig. 7 - 3 Quality Control - Result Texts

For each section text can be entered and / or macros can be selected from the lists as shown in the figure above. To add a macro select it in the list, make sure that the cursor is at the position where you want to insert the macro and click 'Insert'.

The result text can be used as a quality control report by printing it out directly from the result window of the analysis window. The header text is shown once in the beginning of the report, the 'Result Text for Data Point Result' is shown for each data point for which the defined output is valid (in the figure above for all data points that are outside the defined tolerance). The 'Result Text for Total Result' is shown once in the end of the report.

The text from the result window with the settings from the figure above can be seen below.

Quality Control

=====

Name of Datapool:

-

List of Data Series:

Measurement Flow AK6e5 100C n 1

- I 1, P 1 ... I 1, P 22

Result Data Series:

Measurement Flow AK6e5 100C n 1 Quality Control 6

Date: 08.05.2001

Time: 11:37:28 PM

Data series Measurement Flow AK6e5 100C n 1

Measured by: M. Operator

The following data points are outside the defined tolerance:

Data point number 22 with value 189.8539 Pa·s has a relative difference of -0.08 %.

All other data points are inside the defined tolerance.

The sample has passed the quality control test.

8 Creep Recovery <Creep Test>

The analysis methods of this group are used to evaluate the results of creep or creep recovery measurements.

8.1 Creep $J(t)$; J_e0 ; η_0

The creep evaluation 'Creep $J(t)$; J_e0 ; η_0 ' calculates the instantaneous and viscoelastic compliance for the creep and recovery curves as well as the Newtonian compliance and the zero shear viscosity for the creep curve. For the recovery curve the instantaneous compliance and the viscoelastic compliance are calculated. A mean retardation time is calculated for both creep and recovery curve.

The screenshot shows the 'Creep J(t);Je0;eta0' dialog box with the following settings:

- Interval Numbers:** Creep: 1, Recovery: 2. Note: Intervals must be separated by semicolons (e.g. 1;2;3).
- Regressed Regions of Creep Phase:**
 - Equation: $J(t) = J_0 + J_m(t) + J_n(t)$
 - Region 1: Instantaneous Compliance (J_0) - checked
 - Region 2: Viscoelastic Compliance ($J_m(t) = J_m(1 - \exp(-t/\Lambda))$) - checked
 - Region 3: Newtonian Compliance ($J_n(t) = t/\eta_0$) - checked
- Steady State Check:** Slope Changing between Adjacent Time Windows (dropdown), Time Windows: 10
- Regressed Regions of Recovery Phase:**
 - Equation: $J(t) = J_{max} - J_0 - J_m(t)$
 - Region 4: Instantaneous Compliance (J_0) - checked
 - Region 5: Viscoelastic Compliance ($J_m(t) = J_m(1 - \exp(-t/\Lambda))$) - checked
- Known (Given) Values for Creep and Recovery Phase:**
 - J_0 : Λ : t_0 Creep:
 - J_m : η_0 : t_0 Recgv.:
 - J_{max} :
- Result Tables:** Result Table for Creep Phase, Result Table for Recovery Phase

Fig. 8 - 1 Creep $J(t)$; J_e0 ; η_0 - Parameter settings

This method is similar to the 'Creep Regression'. 'Creep Regression' usually gives more exact results because three retardation times are used instead of one.

Please note that the complete data series from a creep recovery respectively a creep measurement should be used as input data, not regions.

8.1.1 Parameter Settings

Interval numbers

Usually, a creep recovery measurement contains two intervals, one for the creep phase and one for the recovery phase. Enter the interval number for each interval. It is possible to define several creep and several recovery intervals by entering the interval number separated by a semicolon. If e.g. only the creep phase should be evaluated, no number needs to be given for the recovery. In that case the parameters for 'Regressed Regions of Recovery Phase' need to be disabled as well.

Regressed Regions of Creep Phase

The creep phase can be divided into three sections as shown in the parameter dialog box. Check the regions which you would like to be calculated. If no creep interval has been defined above, all regions need to be unchecked.

Steady State Check

See below

Regressed Regions of Recovery Phase

Check the regions you would like to be calculated for the recovery phase. If no recovery phase has been defined above, all recovery regions need to be unchecked.

Known (Given) Values for Creep and Recovery Phase

In case any of the variable values given in this section are known you can check the parameter and enter the value.

Show Result Table

If the option 'Show Result Table for ...' is checked the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value. The result tables for the creep and the recovery phase can be activated separately.

8.1.2 Steady state check

The analysis methods checks whether a steady state has been reached at the end of the creep phase. For the determination of the steady state three methods are available. It is also possible to disregard this check by choosing the option 'No Steady State Check'.

Correlation Ration of a Lin. Regression $\gamma(t)=f(t)$

This method calculates a linear regression on the last data points of the creep phase (strain vs. time curve). The number of data points is defined in the text box 'Region Size'. The region size value gives the number of points in percent of the total number of points during the creep phase. As a default value 10 % is recommended. The criterion for the steady state is the correlation ratio of the regressed data which approaches 1. The boundary value is 0.997.

Slope of a linear regression $\log(J(t))=f(\log(t))$

With this method a linear regression is done on a logarithmic curve of the compliance as a function of time. As with the previous method, the data points at the end of the creep curve are used. The value for 'Region Size' gives the number of points for the calculation in percent of the total number of points during the creep phase. As a default value 10 % is recommended. The criterion for the steady state is the correlation ratio of the regressed data which approaches 1. The boundary values are 0.95 and 1.05.

Slope changing between adjacent time windows

For this method the creep curve is divided in the given number of sections (time windows) and a linear regression curve is calculated for each section. The change of slope between from section to section is compared. Steady state has been reached if the change of slope approaches zero. The boundary value is 0.1.

8.1.3 Example

The example shows the creep recovery curve of a polystyrene melt. For the creep phase the zero shear viscosity has been calculated; further, the steady state compliance is stored with the analysis data. The table below contains the data that are shown in the result window of the analysis window.

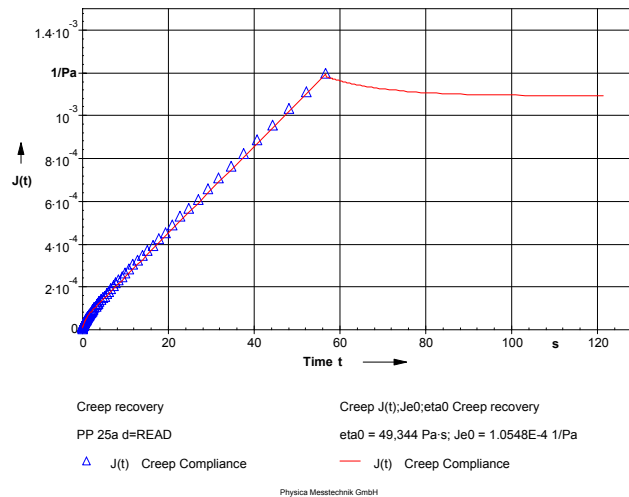


Fig. 8 - 2 Creep J(t); Je0; eta0 - Example (Diagram)

```

Creep Phase
-----
Creep Compliance J(t) = J0 + Jm·(1-exp(-t/Lambda)) + t/eta0

Instantaneous Compliance      J0      : 8.2995E-6 1/Pa
Viscoelastic Compliance      Jm      : 3.7759E-5 1/Pa
Mean Retardation Time        Lambda   : 0.6489 s
Zero Shear Viscosity         eta0    : 49344 Pa·s
Correlation Ratio            Rxy     : 0.9993
Standard Deviation           s(n-1)  : 1.0982E-5 1/Pa

Instant. Deformation         gamma0  : 0.0082958 %
Newtonian Shear Rate        Dn     : 2.0257E-4 1/s
Data Points for Steady State Check : 7
Steady State Criterion      : 0.99992
Steady State                : reached

Recovery Phase
-----
Creep Compliance J(t) = Jmax - J0 - Jm·(1-exp(-t/Lambda))

Instantaneous Compliance      J0      : 1.4907E-5 1/Pa
Viscoelastic Compliance      Jm      : 9.0575E-5 1/Pa
Mean Retardation Time        Lambda   : 13.035 s
Correlation Ratio            Rxy     : 0.99259
Standard Deviation           s(n-1)  : 3.7227E-6 1/Pa

Steady State Compliance     Je0     : 1.0548E-4 1/Pa
Elastic Compliance          Je      : 1.0548E-4 1/Pa
Viscous Compliance          Jv     : 0.0010925 1/Pa
Elastic Share of Compliance  Je/Jmax : 8.81 %
Viscous Share of Compliance  Jv/Jmax : 91.19 %

```

Fig. 8 - 3 Creep J(t); Je0; eta0 - Example (Result Window)

8.2 Creep $J(t;\tau_0)$

This analysis method is used to calculate the $J(t)$ values for the recovery phase. As the compliance is calculated by dividing the current deformation by the shear stress it can only be calculated for the creep phase; during recovery the shear stress is set to zero. To calculate the compliance during the recovery phase the shear stress from the creep phase of the experiment is used.

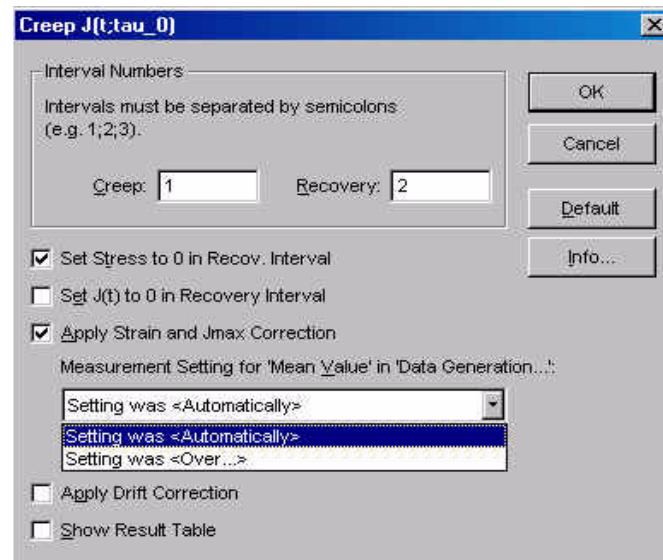


Fig. 8 - 4 Creep $J(t;\tau_0)$ - Parameter settings

8.2.1 Parameter Settings

Interval Numbers

For this analysis method only the interval numbers of the creep and recovery phase need to be entered. In case the measurement contains several creep recovery curves, you can enter all creep interval numbers into the 'Creep' text box as described in the dialog and all recovery interval numbers in the 'Recovery' text box.

Please note that the complete data series from a creep recovery respectively a creep measurement should be used as input data, not regions.

Dismiss Input Data with $\tau > 0$ in Recov. Intv.

If very short data point intervals have been selected, the first data points of the recovery phase may show a shear stress different from zero. This option removes these data points if activated, the points are not used for the analysis.

Set $J(t)$ to 0 in Recovery Interval

If this option is activated, the compliance values for the recovery phase are set to zero. The compliance $J(t)$ is shown for the creep phase only, for the recovery phase $J_r(t)$ is shown. For the x-axis select the interval time.

Apply Time and J_{max} Correction

The values for time and J_{max} from measurements with automatic settings are corrected with this option.

Show Result Table

If the option 'Show Result Table' is checked the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value.

8.2.2 Example

The example shows the creep recovery curve of a polymer melt. The experimental data (triangle symbols) show $J(t)$ for the creep curve and no value for the recovery curve. The calculated curve corresponds to the measurement for the creep phase and shows $J(t, \tau_0)$ for the recovery phase.

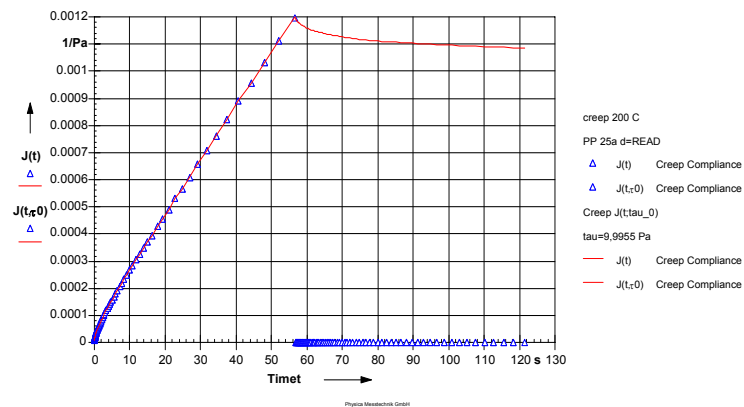


Fig. 8 - 5 Creep $J(t;\tau_0)$ - Example

8.3 Creep Regression

With 'Creep Regression' the instantaneous and viscoelastic compliance for the creep and recovery curves are calculated as well as the Newtonian compliance and the zero shear viscosity for the creep curve. For the recovery curve the instantaneous compliance and the viscoelastic compliance are calculated. Instead of one mean retardation time this method calculates three retardation times for the creep and the recovery curve. Please note that these calculations may take considerable time depending on the capacity of the computer.

Creep Regression

ATTENTION: Calculation can take several minutes on a 450 MHz PC!

Interval Numbers

Creep: Recovery: Intervals must be separated by semicolons (e.g. 1;2;3).

Output Tables in Result Window for

Creep Phase Recovery Phase

Default Info...

Regressed Regions of Creep Phase

$J(t) = J_0 + J_m(t) + J_n(t)$

Region 1: Instantaneous Compliance J_0

Region 2: Viscoelastic Compliance $J_m(t) = \text{SUM}(J_{m_i}(1 - \exp(-(t-t_0)/\text{Lambda}_i))) \quad i=1 \dots 3$

Region 3: Newtonian Compliance $J_n(t) = (t-t_0)/\eta_0$

Steady State Check

Correlation Ratio of a Lin. Regression $\gamma_m(t)=f(t)$ Region Size: %

Regressed Regions of Recovery Phase

$J(t) = J_{\text{max}} - J_0 - J_m(t) + J_{\text{drift}}(t)$

Region 4: Instantaneous Compliance J_0

Region 5: Viscoelastic Compliance $J_m(t) = \text{SUM}(J_{m_i}(1 - \exp(-(t-t_0)/\text{Lambda}_i))) \quad i=1 \dots 3$

Use Drift Correction $J_{\text{drift}}(t) = ((t-t_0)/\tau_0) \cdot d(\gamma_{\text{drift}})/dt$

Known (Given) Values for Creep and Recovery Phase

J_0 : J_{m_1} : Lambda_1 :

J_{max} : J_{m_2} : Lambda_2 :

η_0 : J_{m_3} : Lambda_3 :

t_0 Creep: t_0 Recgv

Fig. 8 - 6 Creep Regression - Parameter settings

Please note that the complete data series from a creep recovery respectively a creep measurement should be used as input data, not regions.

8.3.1 Parameter Settings

Interval numbers

Usually, a creep recovery measurement contains two intervals, one for the creep phase and one for the recovery phase. Enter the interval number for each interval. It is possible to define several creep and several recovery intervals by entering the interval number separated by a semicolon. If e.g. only the creep phase should be evaluated, no number needs to be given for the recovery. In that case the parameters for 'Regressed Regions of Recovery Phase' need to be disabled as well.

Regressed Regions of Creep Phase

The creep phase can be divided into three sections as shown in the parameter dialog box. Check the regions which you would like to be calculated. If no creep interval has been defined above, all regions need to be unchecked.

Steady State Check

See below

Regressed Regions of Recovery Phase

Check the regions you would like to be calculated for the recovery phase. If no recovery phase has been defined above, all recovery regions need to be unchecked. If the option 'Use Drift Correction' is activated, the analysis method compensates for a drift in the recovery phase that can be caused by a very slow rotational movement of the measuring system.

Known (Given) Values for Creep and Recovery Phase

In case any of the variable values given in this section are known you can check the parameter and enter the value.

Show Result Table

If the option 'Show Result Table for ...' is checked the result field includes a table with the x-variable, the input values of the y-variable, the calculated values of the y-variable and the error between input and calculated value. The result tables for the creep and the recovery phase can be activated separately.

8.3.2 Steady state check

The analysis methods checks whether a steady state has been reached at the end of the creep phase. For the determination of the steady state three methods are available. It is also possible to disregard this check by choosing the option 'No Steady State Check'.

Correlation Ration of a Lin. Regression $\gamma(t)=f(t)$

This method calculates a linear regression on the last data points of the creep phase (strain vs. time curve). The number of data points is defined in the text box 'Region Size'. The region size value gives the number of points in percent of the total number of points during the creep phase. As a default value 10 % is recommended. The criterion for the steady state is the correlation ratio of the regressed data which approaches 1. The boundary value is 0.997.

Slope of a linear regression $\log(J(t))=f(\log(t))$

With this method a linear regression is done on a logarithmic curve of the compliance as a function of time. As with the previous method, the data points at the end of the creep curve are used. The value for 'Region Size' gives the number of points for the calculation in percent of the total number of points during the creep phase. As a default value 10 % is recommended. The criterion for the steady state is the correlation ratio of the regressed data which approaches 1. The boundary values are 0.95 and 1.05.

Slope changing between adjacent time windows

For this method the creep curve is divided in the given number of sections (time windows) and a linear regression curve is calculated for each section. The change of slope between from section to section is compared. Steady state has been reached if the change of slope approaches zero. The boundary value is 0.1.

8.3.3 Example

The example shows the creep recovery curve of a polystyrene melt. For the creep phase the zero shear viscosity has been calculated; further, the steady state compliance is stored with the analysis data.

The table below contains the data that are shown in the result window of the analysis window. The calculated retardation times are only shown in the result window. The result window further gives information about how many data points have been used for steady state check and whether a steady state has been reached.

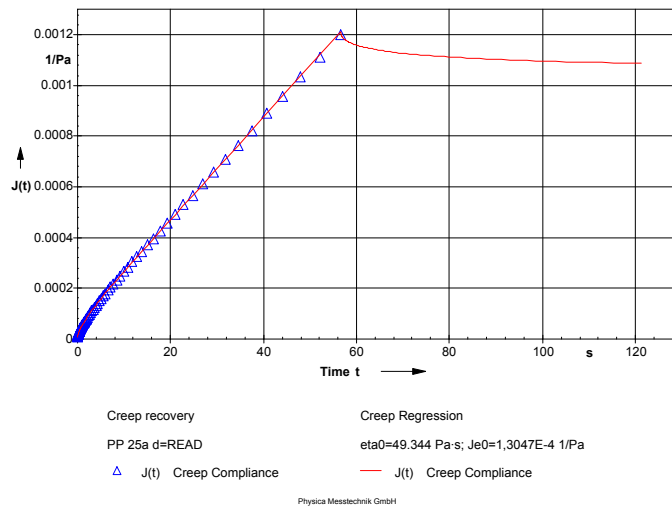


Fig. 8 - 7 Creep Regression - Example (Diagram)

```

Creep Regression
=====
Name of Datapool:
-
List of Data Series:
  Creep recovery
Result Data Series:
  Creep Regression Creep recovery

PARAMETERS:
Interval Numbers of Creep Intervals      : 1
Interval Numbers of Recovery Intervals   : 2
Region 1:                                J0      : 0n
Region 2:                                Jr(t)   : 0n
Region 3:                                Jn(t)   : 0n
Region 4:                                J0      : 0n
Region 5:                                Jr(t)   : 0n
Type of Steady State Check                : Corr. Ratio of gamma(t)=f(t)
Range for Steady State Check              : 10 %
Max. Creep Compliance                     Jmax    : Automatic
Start of Creep Phase                      t0      : Automatic
Start of Recovery Phase                   t0      : Automatic
Result Table for Creep Phase              : 0n
Result Table for Recovery Phase           : 0n

ANALYSIS RESULTS:
Number of Input Data Points               : 149
Number of Data Points Creep Phase        : 75
Number of Data Points Recovery Phase     : 74

Mean Stress                               tau0    : 9.9955 Pa
Start of Creep Phase                      t0      : 0.0086588 s
Start of Recovery Phase                   t0      : 56.673 s
Max. Creep Compliance                     Jmax    : 0.0011979 1/Pa

Creep Phase
-----
Creep Compliance  $J(t)=J_0+\text{SUM}(J_{n_i} \cdot (1-\exp(-(t-t_0)/\text{Lambda}_i))) + (t-t_0)/\text{eta}$ 

Instantaneous Compliance                  J0      : 0 1/Pa
Viscoelastic Compliance                   Jm_1    : 4.3629E-5 1/Pa
Viscoelastic Compliance                   Jm_2    : 1.0919E-5 1/Pa
Viscoelastic Compliance                   Jm_3    : 9.5532E-6 1/Pa
Mean Retardation Time                     Lambda_1 : 2.7494 s
Mean Retardation Time                     Lambda_2 : 0.16802 s
Mean Retardation Time                     Lambda_3 : 0.0020205 s
Zero Shear Viscosity                      eta0    : 49344 Pa·s
Correlation Ratio                          Rxy     : 0.99996
Standard Deviation                         s(n-1)  : 2.4079E-6 1/Pa

Instant. Deformation                      gamma0   : 0 %
Newtonian Shear Rate                       Dn      : 2.0257E-4 1/s
Data Points for Steady State Check         : 7
Steady State Criterion                     : 0.99992
Steady State                               : reached

Recovery Phase
-----
Creep Compliance  $J(t)=J_{\text{max}}-J_0-\text{SUM}(J_{n_i} \cdot (1-\exp(-(t-t_0)/\text{Lambda}_i)))$  i=1..

Instantaneous Compliance                  J0      : -1.596E-7 1/Pa <-- WARNING!
Viscoelastic Compliance                   Jm_1    : 6.8592E-5 1/Pa
Viscoelastic Compliance                   Jm_2    : 4.1811E-5 1/Pa
Viscoelastic Compliance                   Jm_3    : 2.0224E-5 1/Pa
Mean Retardation Time                     Lambda_1 : 48.775 s
Mean Retardation Time                     Lambda_2 : 7.0269 s
Mean Retardation Time                     Lambda_3 : 1.0358 s
Correlation Ratio                          Rxy     : 0.99964
Standard Deviation                         s(n-1)  : 7.1438E-7 1/Pa

Steady State Compliance                   Je0     : 1.3047E-4 1/Pa
Elastic Compliance                         Je      : 1.3047E-4 1/Pa
Viscous Compliance                         Jv      : 0.0010675 1/Pa
Elastic Share of Compliance                Je/Jmax : 10.89 %
Viscous Share of Compliance                Jv/Jmax : 89.11 %

```

Fig. 8 - 8 Creep Regression - Example (Result Window)

9 <Master Curve>

Time temperature superposition can be used to shift data measured at one temperature to another to be able to get information about the material for a wider time range. Further, it is possible to shift the data to a temperature at which no measurement has been carried out. A temperature or frequency shift is only possible for so-called thermorheologically simple materials; e.g. polymer melts far from the glass temperature and polymer solutions belong to this group.

9.1 Master Curve

The method can automatically generate the master curve from frequency sweeps at different temperatures and calculate a frequency sweep curve from this master curve at a user-defined temperature value. It is also possible to just calculate the master curve or use a master curve as input data and do an inverse shift to generate frequency sweep data. The method 'Master Curve' combines 'Shift Master Curve' and 'Shift Inverse Master Curve'.

The screenshot shows the 'Master Curve' dialog box with the following settings:

- Calculation Mode:** Convert Variables for a Different Temperature
- Input Variables:**
 - F(ω) Shift variable is a function of frequency
 - F(t) Shift variable is a function of time
 - F1(ω), F2(ω) Shift variables are two different functions of frequency
 - F1(ω): G' Storage Modulus
 - F2(ω): G'' Loss Modulus
- Calculation Parameters:**
 - Target Temp.: 200 °C
 - Setting: Manual
 - Shift Direction: Only Horizontal Range: 30 %
 - Use only input data within a defined range of x-values
 - Min.: 1E-6 1/s Max.: 1E+3 1/s
 - Don't use the following input data points for calculation of shift factors but shift them nevertheless
 - Define points relatively Lower: 10 % of points Upper: 20 % of points
 - Define points absolutely
- Additional Frequency and Time Independent Result Variables:**
 - Variable: |G'|/sin(δ) |G''|/sin(δ)
 - Defined Var.: (empty field)
 - Buttons: Append, Delete

On the left side, there is a flow diagram: Input Data → Master Curve → Result Data at 200 °C. On the right side, there are buttons: OK, Cancel, Default, and Info...

Fig. 9 - 1 Mastercurve - Parameter settings

9.1.1 Calculation Mode

Select the calculation mode according to whether you want to calculate mastercurve and frequency / time dependent data at a certain temperature, the mastercurve only or frequency / time dependent data from an existing master curve.

- **Convert Variables for a Different Temperature**
Calculates the mastercurve from the input data and reconverts the mastercurve to the original variables at a user selected temperature value. Input data can be e. g. frequency sweeps or stress relaxation tests at several temperatures.
- **Calculate Master Curve**
Calculates the mastercurve from the input data. Input data can be e. g. frequency sweeps or stress relaxation tests at several temperatures.
- **Calculate Result Variables from Master Curve**
Reconverts a mastercurve to the original rheological data at a user selected temperature. The input data series has to be a mastercurve.

9.1.2 Input Variables

To shift frequency dependent data select the option $F(w)$ or $F1(w)$, $F2(w)$ and select the variable(s) from the list. If the second option is selected, two variables can be selected for shifting. To shift time dependent data select the option $F(t)$ and select the variable from the list. Common variables to shift are storage and loss modulus or the relaxation modulus.

For the mode 'Calculate Result Variables from Master Curve' select whether the shift variables are functions of the frequency or the time, then select and append each variable you would like to shift.

9.1.3 Calculation Parameters

The available calculation parameters depend on the choice made for the calculation mode. Below all parameters are described.

- 'Target Temp'.
Select the temperature to which the master curve data should be reconverted.
- 'Setting'
If automatic setting selected, all remaining calculation parameters are set by the software. With manual setting, the parameters described below can be set by the user.
- 'Shift Direction' and 'Range'
Choose one of the shifting options 'Only Horizontal' or 'Horiz. and Vertical'. The horizontal shift has a shorter calculation time, the horizontal and vertical shift sometimes gives a better fit. If horizontal and vertical shift has been selected, the value for the maximum shifting range is used to limit the shifting in the vertical direction. The recommended setting for the shifting range is 100 %.
- Use only input data within a defined range of x-values
Check this option to limit the range of the input data, e.g. to exclude scatterly measuring data. Enter the minimum and maximum value for the range of input data.
- Don't use the following input data...
Check this option to exclude data points at the beginning and the end to the measurement from the calculation. These points are still shifted with the shifting factors determined from the remaining data points. The range of data points, that should be excluded, can be set using a percentage or an absolute number of points.

9.1.4 Additional Result Variables / Frequency and Time Independent Variables

- Additional Result Variables
Select each variable you would like to shift and add it to the list by clicking 'Append'. To delete a selected variable, highlight it in the list and click 'Delete'.
- Frequency and Time Independent Variables
Select and append any variables you would like to store in the output data series.

9.2 Shift Master Curve

(replaces 'Shift G' \rightarrow aT;bT', 'Shift G'' \rightarrow aT;bT', 'Shift G(t) \rightarrow aT;bT', 'Shift tan(delta) \rightarrow aT' and 'Shift G';G'' \rightarrow aT;bT')

The method 'Shift Master Curve' can be used to automatically shift frequency or time dependent data. The shift can either be done horizontally or horizontally and vertically. The vertical shift factor is usually small; it is due to the temperature dependent changes of the sample density. This temperature dependency is usually very small.

The screenshot shows the 'Shift Master Curve' dialog box with the following settings:

- Variables, from which the shift factors are calculated:**
 - F(ω) Shift variable is a function of frequency
 - F1(ω), F2(ω) Shift variables are two different functions of frequency
 - F(t) Shift variable is a function of time
- F(ω):** G' Storage Modulus
- Calculation Parameters:**
 - Only Horizontal Shift Horiz. and Vert. Shift (Long Calculation Time!)
 - Maximum Shifting Range: 10 %
 - Use only input data within a defined range of x-values
 - Min.: 1E-6 1/s Max.: 1E+3 1/s
 - Don't use the following input data points for calculation of shift factors but shift them nevertheless
 - Define points relatively Define points absolutely
 - Lower: 0 % of points Upper: 0 % of points
- Additional variables to be put into output data series:**
 - Variable: No. Datapoint Number
 - Defined Var.: T Temperature
 - Buttons: Append, Delete
- Put output values into separate intervals, one interval for each shifted data series

Fig. 9 - 2 Shift Master Curve - Parameter settings

9.2.1 Variables

To shift frequency dependent data select the option F(ω) or F1(ω), F2(ω) and select the variable(s) from the list. If the second option is selected, two variables can be selected for shifting. To shift time dependent data select the option F(t) and select the variable from the list. Common variables to shift are storage and loss modulus.

9.2.2 Calculation Parameters

- **Only Horizontal Shift / Horiz. and Vert.Shift / Maximum Shifting Range**
Choose one of the shifting options. The horizontal shift has a shorter calculation time, the horizontal and vertical shift sometimes gives a better fit. If horizontal and vertical shift has been selected, the value for the maximum shifting range is used to limit the shifting in the vertical direction. The recommended setting for the shifting range is 100 %.
- **Use only input data within a defined range of x-values**
Check this option to limit the range of the input data, e.g. to exclude scatterly measuring data. Enter the minimum and maximum value for the range of input data.
- **Don't use the following input data...**
Check this option to exclude data points at the beginning and the end to the measurement from the calculation. These points are still shifted with the shifting factors determined from the remaining data points. The range of data points, that should be excluded, can be set using a percentage or an absolute number of points.

9.2.3 Example

The diagram shows the master curve of a low density polyethylene. The measurements have been carried out at 170 °C, 190 °C, 210 °C and 230 °C. The data have been shifted using 170 °C as the reference temperature.

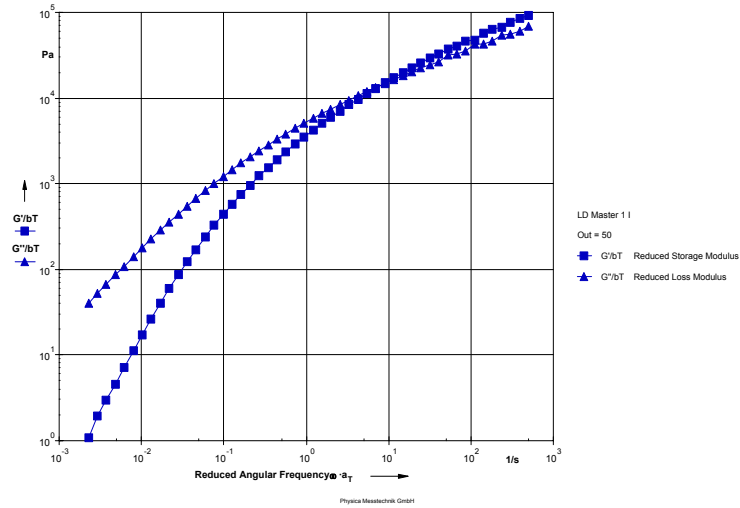


Fig. 9 - 3 Shift Master Curve - Example

9.3 Shift Manual

The method 'Shift Manual' is used to shift frequency or time dependent data manually, for example to check the effect of changing the shift factors that have been calculated by the 'Shift Master Curve' method. The shift factors aT and bT are entered by the user, as well as the reference temperature and the variables that are to be shifted.

The screenshot shows the 'Shift Manual' dialog box with the following settings:

- Shifting Direction:** Horizontal and Vertical Shift
- Given Shift Factors:**
 - Hor. Shift Factor aT : 0.113, $\log(aT)$: -0.94692156
 - Vert. Shift Factor bT : 1.49, $\log(bT)$: 0.17318627
- Type of variables to be shifted:** $F(\omega)$ (Shift variables are functions of frequency)
- Reference Temperature T_0 of Master Curve:** 0 °C
- Variables to Be Put into Output Data Series:**
 - Variable: G'' Loss Modulus
 - Defined Var.: G', Storage Modulus; G'', Loss Modulus
- Put output values into separate intervals, one interval for each shifted data series

Fig. 9 - 4 Shift Manual - Parameters settings

9.3.1 Parameter Settings

Shifting Direction

Select whether to shift the data in horizontal direction only, or horizontally and vertically. A vertical shift accounts for the temperature dependent change of the sample density; it is usually small.

Given Shift Factors

Enter the values for the horizontal and vertical shift factor. The text box for the vertical shift factor is only available if 'Horizontal and Vertical Shift' has been selected. For the data series whose measurement temperature is used as the reference temperature enter the value 1. If the manual shift is used to adjust the

results from the 'Shift Master Curve' method, the shift factors calculated there can be used for a start. Please note that each temperature requires different shift factors. It may therefore be necessary to carry out the manual analysis separately for each input temperature.

Type of variables to be shifted

Select whether the input data are functions of the frequency (oscillation data) or of the time (e.g. stress relaxation data).

Reference Temperature T_0 of Master Curve

Enter the temperature to which the input data should be shifted.

Variables to Be Put into Output Data Series

Select each variable you would like to shift and add it to the list by clicking 'Append'. To delete a selected variable, highlight it in the list and click 'Delete'.

9.3.2 Example

The example shows the results of the manual shift of a polyethylene melt with a reference temperature of 170 °C. The measurements have been carried out at 170 °C, 200 °C and 230 °C.

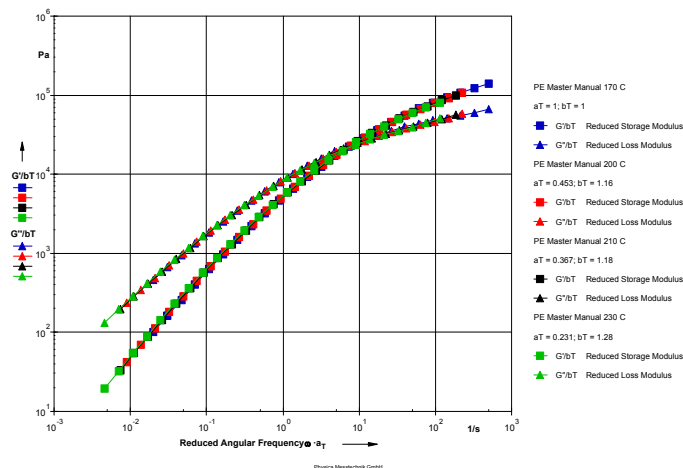


Fig. 9 - 5 Shift Manual - Examples

9.4 Shift Inv. Master Curve

With this method it is possible to generate time or frequency dependent data from a master curve. The result will cover the same frequency or time range as the master curve.

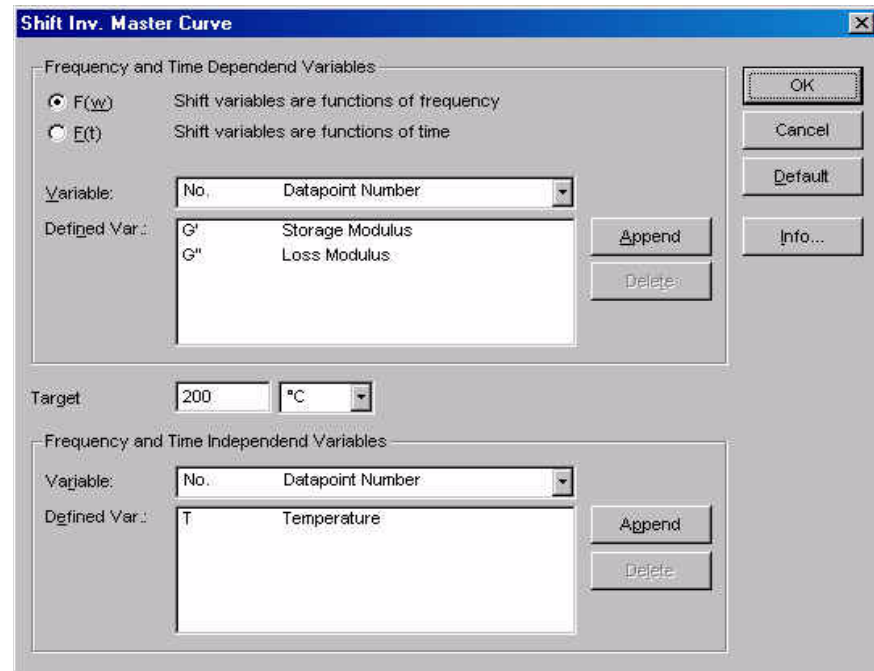


Fig. 9 - 6 Shift Inv. Master Curve - Parameters settings

9.4.1 Parameter Settings

Frequency and Time Dependend Variables

Select whether the shift variables are functions of the frequency or the time, then select and append each variable you would like to shift.

Target

Enter the temperature value to which you would like to shift the data. This can be one of the measurement temperatures of the input data for the original master curve or a temperature value inside the measured range of temperatures.

Frequency and Time Independend Variables

Select and append any variables you would like to store in the output data series.

9.4.2 Example

The example contains data for a low density polyethylene. The measurement had been carried out at 170 °C, 190 °C, 210 °C and at 230 °C; the data have been shifted to a master curve with a reference temperature of 170 °C.

The diagram shows the original measurement data at 170 °C and 230 °C (filled symbols) and the results from the inverse shifting (hollow symbols). It would also be possible to shift the data to a temperature which has not been measured. It can be seen that the master curve and inverse shift can considerably broaden the range where data can be obtained for a sample without having to measure at the required frequency range.

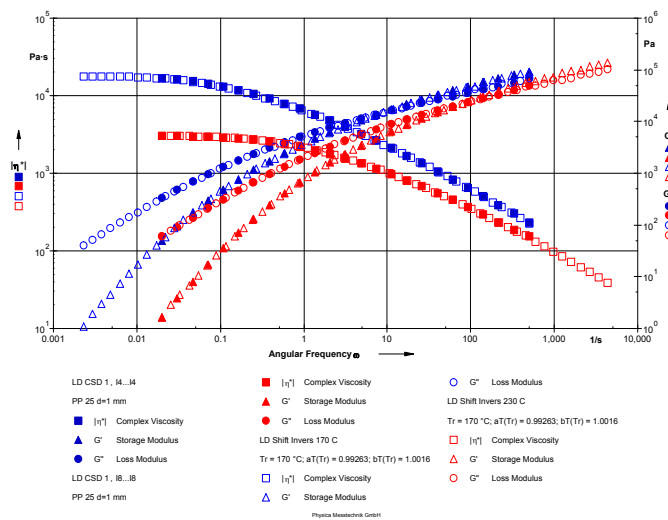


Fig. 9 - 7 Shift Inv. Master Curve - Examples

10 <Spectrum Relaxation>

The methods of this group can be used to calculate the relaxation time spectrum from oscillation data or from stress relaxation measurements. Further, it is possible to convert the data from a relaxation time spectrum to oscillatory or stress relaxation data. This can e. g. be used to generate low frequency oscillation data from a stress relaxation measurement. Further, the relaxation time spectrum can be used as input data for the MMD evaluation.

10.1 Continuous Relaxation Spectrum and Continuous EPR Relaxation Spectrum

These two methods are using identical parameter dialog boxes, they are therefore described in one chapter. The 'Continuous EPR Relaxation Spectrum' uses a different regularization method (edge preserving regularization method) which often gives a better estimation of the calculated spectrum.

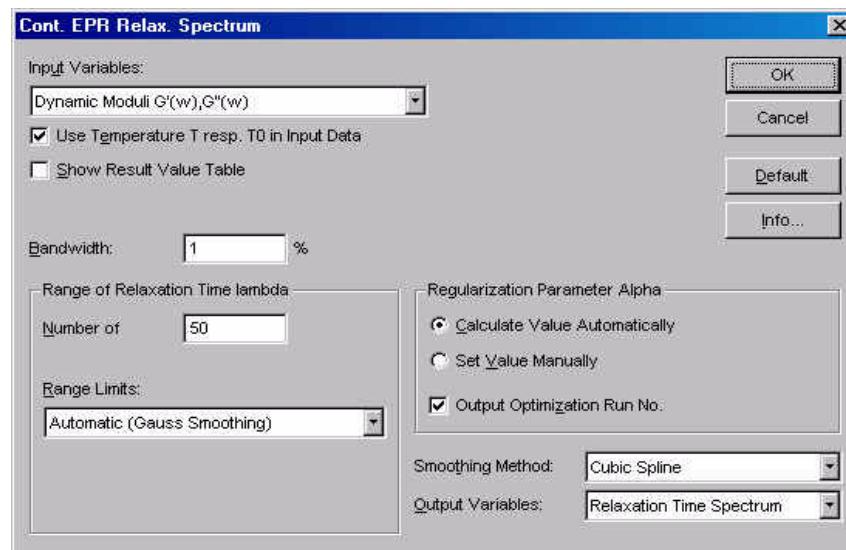


Fig. 10 - 1 Continuous (EPR) Relaxation Time Spectrum - Parameter settings

10.1.1 Parameter Settings

Input Variables

Select the input variables from the list depending on the type of input data. A relaxation time spectrum can be calculated from oscillation or stress relaxation data or from a master curve.

Use Temperature T resp. T_0 in Input Data

If this option is activated, the temperature values from the input data series are stored in the analysis result. This option requires, that the temperature is available in the input data series, otherwise an error message will be shown when the analysis is carried out.

Show Result Value Table

With this option the input and output data points can be listed in the result window of the analysis window. The input data points will be listed with their input value as well as with the value calculated from the relaxation time spectrum. The output data points are the relaxation times, H (l) with the minimum and maximum value and the estimated error. The error value is dependent on the selected parameter alpha; it should be as close to one as possible.

Bandwidth

The bandwidth is the relative error of the input data, it is used for the error estimation and for the smoothing of the input data.

Range of Relaxation Time λ

Enter the number of relaxation time values that you wish to be calculated. The maximum value is 90. The range limits are selected from the list, the default setting is 'Automatic (Gauss Smoothing)' which gives a wide extrapolation of the data beyond the time scale of the input data. 'Edge Smoothing' gives a limited extrapolation of the input data, with 'Full Spectrum' no extrapolation is done. To set the minimum and maximum value manually, select the option 'Set range manually' and enter the values.

Regularization Parameter Alpha

Select whether let the software calculate the parameter automatically or to enter the value manually. The value for alpha should be selected in a way that the error value (see above) is as close to one as possible.

If 'Output Optimization Run No.' is selected the number of iterations that is used for the automatic calculation of alpha is shown in the result window of the analysis window.

Smoothing Method / Output Variables

If 'Cubic Spline' is selected, the spectrum is calculated from smoothed input data; the maximum deviation of the calculated data is given by the bandwidth (see above). As output variables you can select either the smoothed input data, e.g. for comparison, or the relaxation time spectrum. Without smoothing, only the relaxation time spectrum is calculated. Smoothing should be selected, e.g. if a master curve is used as input data.

10.1.2 Example

The example shows the relaxation time spectrum of a polystyrene sample. The curve with the unfilled symbols has been calculated from the full master curve, for the other only part of the master curve has been used. As input data the part has been selected where it can be assumed that the data are correct, i.e. not influenced by side effects. This curve corresponds more to the theoretical shape of a relaxation time spectrum. For the calculation of the MMD from the spectrum this curve should be used if a Rouse correction is not available.

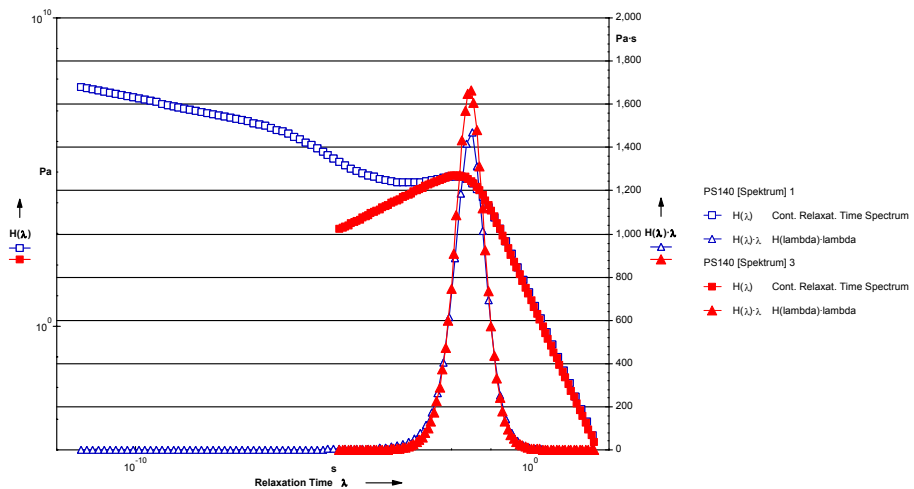


Fig. 10 - 2 Continuous (EPR) Relaxation Time Spectrum - Example

10.2 Inverse Continuous Relaxation Spectrum

This method calculates oscillation or stress relaxation data from a relaxation time spectrum. This can, e. g. be used to check the quality of the calculation of the relaxation time spectrum or to generate the required data from another type of measurement. Please observe that the plausibility of the calculated data should be checked for those time scales that are outside the measured range.

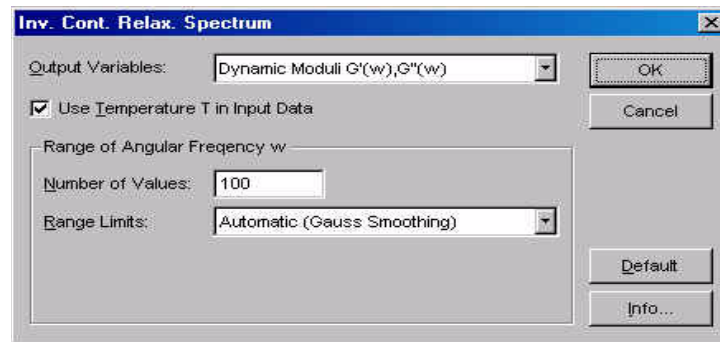


Fig. 10 - 3 Inverse Continuous Relaxation Time Spectrum - Parameter settings

10.2.1 Parameter Settings

Output variables

Select the type of output variables you would like the analysis method to calculate. You can choose between dynamic moduli and relaxation modulus.

Use Temperature T in Input Data

If activated, the temperature values of the input data series are stored into the analysis result. This option should only be checked, if the input data contain the temperature, otherwise an error message will be shown.

Range of Angular Frequency / Time

The range limits are selected from the list, the default setting is 'Automatic (Gauss Smoothing)'. Gauss smoothing calculates the minimum and maximum value from the longest and shortest relaxation time of the input data. 'Edge Smoothing' gives a limited restriction of the input data, with 'Full Spectrum' no restriction is done. To set the minimum and maximum value manually, select the option 'Set range manually' and enter the values.

11 <Spectrum Retardation>

These methods allow to calculate the retardation time spectrum respectively to calculate the retardation time spectrum to e.g. creep data.

11.1 Continuous Retardation Spectrum and Continuous EPR Retardation Spectrum

The 'Continuous Retardation Spectrum' and 'Continuous EPR Retardation Spectrum' are used to calculate the retardation time spectrum from the creep compliance or dynamic compliances. The range of retardation times can be selected. These methods are using (almost) identical parameter settings, although the order of the parameters in the dialog boxes differs slightly. The 'Continuous EPR Retardation Spectrum' uses a different regularization method (edge preserving regularization method) which often gives a better estimation of the calculated spectrum.

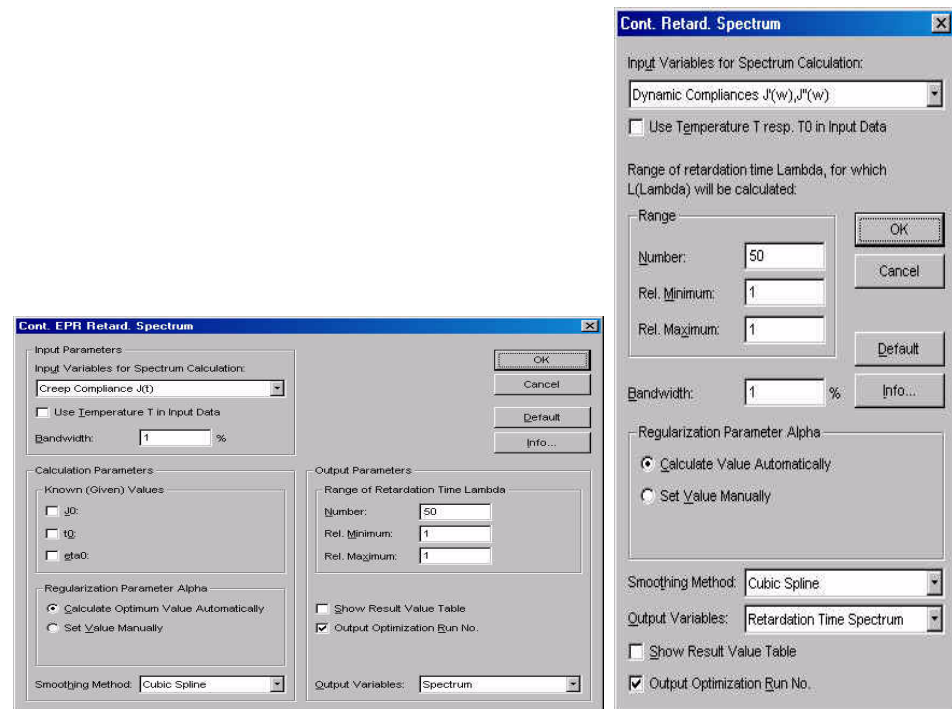


Fig. 11 - 1 Continuous (EPR) Retardation Time Spectrum - Parameter settings

11.1.1 Parameter Settings

Input Variables for Spectrum Calculation

Select the variables from the list. The retardation time spectrum can be calculated from the creep compliance, dynamic compliances or the reduced compliance from a master curve.

Use Temperature T in Input Data

If this option is activated, the temperature values from the input data series are stored in the analysis result. This option requires, that the temperature is available in the input data series, otherwise an error message will be shown when the analysis is carried out.

Bandwidth

The bandwidth is the relative error of the input data, it is used for the error estimation and for the smoothing of the input data.

Calculation Parameters

These parameters are only available if the creep compliance or reduced creep compliance have been selected as input data. Check any of the variables J_0 , t_0 and η_0 , if the value is given or known, and enter the value in the respective text box.

The selection of the calculation parameters is only available for the EPR method.

Regularization Parameter Alpha

Select whether let the software calculate the parameter automatically or to enter the value manually. The value for alpha should be selected in a way that the error value (see above) is as close to one as possible.

If 'Output Optimization Run No.' is selected the number of iterations that is used for the automatic calculation of alpha is shown in the result window of the analysis window.

Range of Retardation Time λ

Enter the number of relaxation time values that you wish to be calculated. The maximum value is 90. Further, you can enter the minimum and the maximum value.

Show Result Value Table

With this option the input and output data points can be listed in the result window of the analysis window. The input data points will be listed with their input value as well as with the value calculated from the relaxation time spectrum. The output data points are the relaxation times, $H(l)$ with the minimum and maximum value and the estimated error. The error value is dependent on the selected parameter α ; it should be as close to one as possible.

Smoothing Method / Output Variables

If 'Cubic Spline' is selected, the spectrum is calculated from smoothed input data; the maximum deviation of the calculated data is given by the bandwidth (see above). As output variables you can select either the smoothed input data, e.g. for comparison, or the relaxation time spectrum. Without smoothing, only the relaxation time spectrum is calculated. Smoothing should be selected, e.g. if a master curve is used as input data.

11.2 Inverse Continuous Retardation Spectrum

This method calculates creep compliance or dynamic compliance data from a retardation time spectrum. This can, e. g. be used to check the quality of the calculation of the retardation time spectrum or to generate the required data from another type of measurement. Please observe that the plausibility of the calculated data should be checked for those time scales that are outside the measured range.

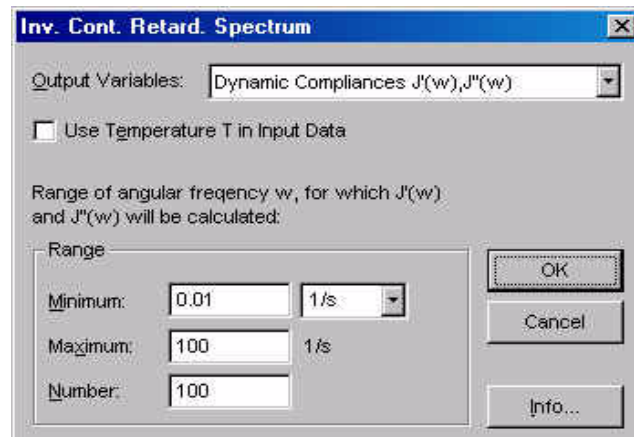


Fig. 11 - 2 Inverse Continuous Retardation Time Spectrum - Parameter Settings

11.2.1 Parameter Settings

Output variables

Select the type of output variables you would like the analysis method to calculate. You can choose between dynamic compliance and creep compliance.

Use Temperature T in Input Data

If activated, the temperature values of the input data series are stored into the analysis result. This option should only be checked, if the input data contain the temperature, otherwise an error message will be shown.

Range of Angular Frequency / Time

Depending on the selected variable you have to enter the frequency range or the time range for which the data should be calculated. Enter minimum and maximum value as well as the number of data points.

12 <Spectrum Conversion>

The spectrum conversion methods are used to generate the relaxation time spectrum from the retardation time spectrum or the other way around. A spectrum conversion is used e.g. if oscillation data are to be generated from creep data.

12.1 Continuous Spectrum $H(\lambda) \rightarrow L(\lambda)$

This method converts the relaxation time spectrum $H(t)$ to the retardation time $L(t)$ spectrum.

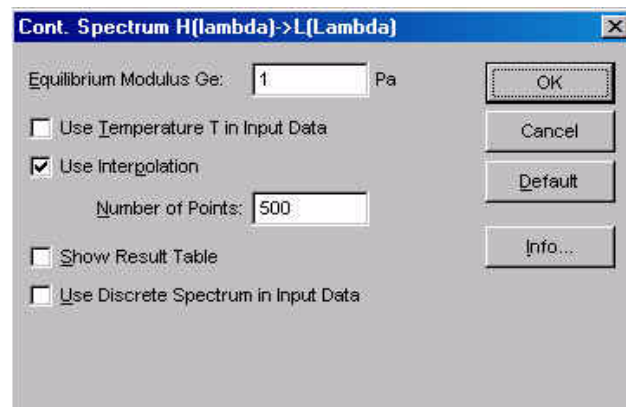


Fig. 12 - 1 Continuous Spectrum $H(t) \rightarrow L(t)$ - Parameter settings

12.1.1 Parameter Settings

Equilibrium Modulus G_e

Enter the value of the equilibrium modulus.

Use Temperature T in Input Data

If activated, the temperature values of the input data series are stored into the analysis result. This option should only be checked, if the input data contain the temperature, otherwise an error message will be shown.

Use Interpolation / Number of Points

This option carries out a cubic spline interpolation of the input data which can be used to change the number of data points. This number can be entered in the text box.

Show Result Value Table

With this option the input and output data points can be listed in the result window of the analysis window.

Use Discrete spectrum in Input Data

This option uses data from the discrete relaxation time spectrum for the calculation. It should always be enabled unless an error message is shown (Rheoplus 0013).

12.2 Continuous Spectrum L(λ) -> H(λ)

This method calculates the continuous retardation time spectrum from the continuous relaxation time spectrum.

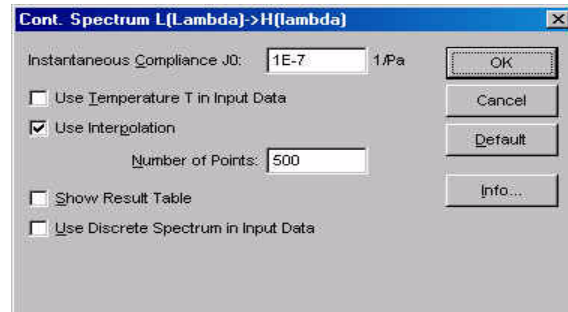


Fig. 12 - 2 Continuous Spectrum L(l) -> H(l) - Parameter settings

12.2.1 Parameter Settings

Instantaneous Compliance J0

Enter the value for the instantaneous compliance J0. The value can be taken from the creep analysis.

Use Temperature T in Input Data

If activated, the temperature values of the input data series are stored into the analysis result. This option should only be checked, if the input data contain the temperature, otherwise an error message will be shown.

Use Interpolation / Number of Points

This option carries out a cubic spline interpolation of the input data which can be used to change the number of data points. This number can be entered in the text box.

Show Result Value Table

With this option the input and output data points can be listed in the result window of the analysis window.

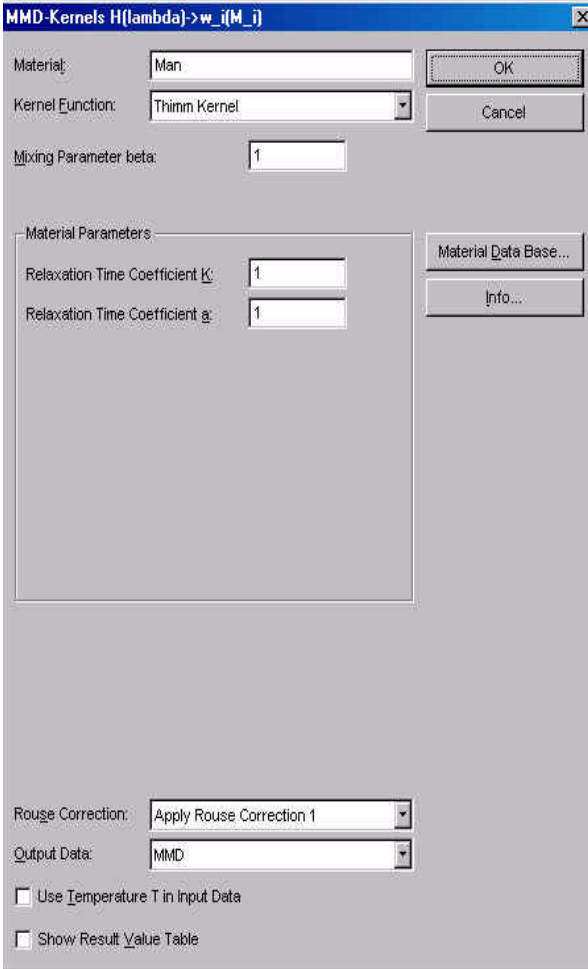
Use Discrete spectrum in Input Data

This option uses data from the discrete relaxation time spectrum for the calculation. It should always be enabled unless an error message is shown (Rheoplus 0013).

13 <MMD Molar Mass Distribution>

13.1 MMD Kernels $H(\lambda) \rightarrow w_i(M_i)$

This method is used to calculate the molar mass distribution from the relaxation time spectrum. For this calculation there are several kernels available. For each kernel function, it is possible to enter the relevant coefficients manually or to use one of the material types stored in the material data base.



The screenshot shows a dialog box titled "MMD-Kernels H(λ)->w_i(M_i)". The dialog contains the following fields and controls:

- Material:** A text box containing "Man" and an "OK" button.
- Kernel Function:** A dropdown menu showing "Thimm Kernel" and a "Cancel" button.
- Mixing Parameter beta:** A text box containing "1".
- Material Parameters:** A section containing:
 - Relaxation Time Coefficient K:** A text box containing "1".
 - Relaxation Time Coefficient a:** A text box containing "1".
 - Material Data Base...:** A button.
 - Info...:** A button.
- Rouse Correction:** A dropdown menu showing "Apply Rouse Correction 1".
- Output Data:** A dropdown menu showing "MMD".
- Use Temperature T in Input Data
- Show Result Value Table

Fig. 13 - 1 MMD Kernels $H(\lambda) \rightarrow w_i(M_i)$ - Parameter settings

13.1.1 Parameter Settings

Material

Enter the material name or click 'Material Data Base'. For a number of materials at certain temperatures the kernel parameters have been determined and tested by comparison with other methods for the determination of the molar mass distribution. Where available, the data base settings should be used.

Kernel Function

Select the kernel function you wish to use from the list. If the material data base is used, the kernel function can be selected there as well.

Mixing Parameter beta / Material Parameters / Regularization Parameter alpha

The number and type of these parameters depends on the selected kernel function. Please refer to the relevant literature for detailed information. The theory behind the calculation of the MMD exceeds the scope of this manual. The material data base contains the parameters for a number of materials. These are shown, if a material has been selected from the data base; they can be edited manually. The regularization parameter alpha determines the sensitivity of the calculation. The smaller the value, the more details of the MMD are visible but problems may occur with the mathematical stability. The higher the value the smoother the MMD curve.

Rouse Correction

If selected, the short time range of the spectrum is corrected by calculating the Rouse portion and subtracting it from the input spectrum data.

Output Data

Select whether to calculate the molar mass distribution, the Rouse spectrum or the entanglement spectrum which is the input spectrum minus the Rouse spectrum. The last two options are only available if 'Subtract Rouse Spectrum' has been enabled.

Use Temperature T in Input Data

If activated, the temperature values of the input data series are stored into the analysis result. This option should only be checked, if the input data contain the temperature, otherwise an error message will be shown.

Show Result Value Table

With this option the input and output data points can be listed in the result window of the analysis window.

13.1.2 The Material Data Base

To use the material data base select the data base in the list 'Work with'. Then highlight the material and the group appropriate for your sample. Click 'OK' to close the dialog box and confirm to save the changes when prompted.

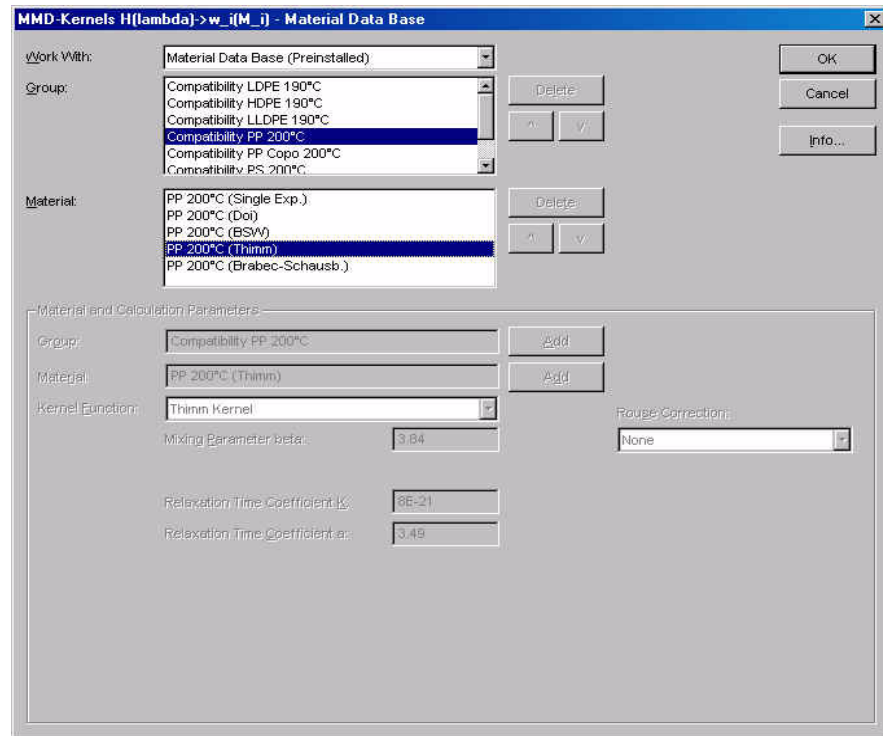


Fig. 13 - 2 Material data base for MMD calculation

The parameters for the selected kernel are shown in the material data base dialog box as inactive but can be edited in the main parameter dialog box.

To add more materials to the data base, select 'Material Data Base (User Defined)' in the 'Work with' list, enter a group name in the lower part of the dialog box and click 'Add'. Then highlight the group name in the list, enter a material name and select a kernel function. Enter the parameters and select a Rouse correction from the list. Then click 'Add'. The user defined materials can then be selected and used.

13.1.3 Example

The example shows the molar mass distribution of a reference polymer, a polystyrene sample. The M_w is very close to the expected value of 140 kg/mol. The MMD has been calculated using the Thimm kernel with the standard parameters for a polystyrene at 200 °C.

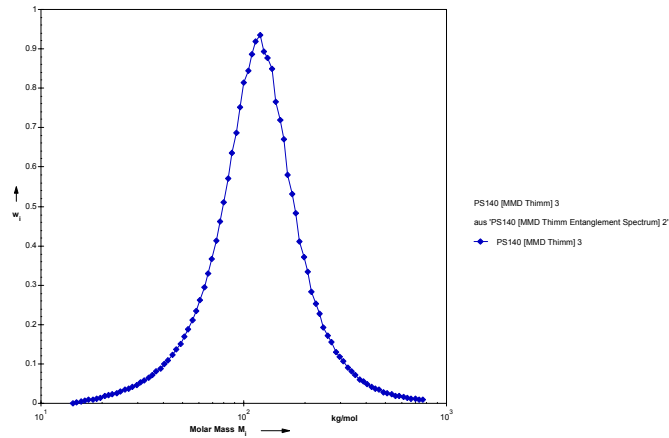


Fig. 13 - 3 Molar Mass Distribution - Example

13.2 MMD Bimodal H(λ) -> $w_i(M_i)$

As the method 'MMD Kernels H(λ) -> $w_i(M_i)$ ' the bimodal method calculates the molar mass distribution from the relaxation time spectrum of a material. The difference is, that here the user can select whether the distribution curve should be unimodal or bimodal. Thus the result curve will always be 'ideal' curves.

The selection of kernels and the material database as well as most other settings are identical to those of that method. Therefore, please refer to "MMD Kernels H(λ) -> $w_i(M_i)$ " for more information on these settings.

Fig. 13 - 4 MMD Bimodal H(λ) -> $w_i(M_i)$ - Parameter settings

13.2.1 Parameter Settings

Given Distribution Form

Select the required curve form from the list. The available options are unimodal, bimodal or automatic.

Ratio (50% 100%)

This setting is only available if bimodal has been selected as the distribution form. It allows to weigh between the two components of a mixture. The available distributions are log-normal or Schulz.

13.2.2 Example

The figure below shows the molar mass distribution for a polystyrene melt using a unimodal distribution. The selected kernel is the Tuminello-Kernel.

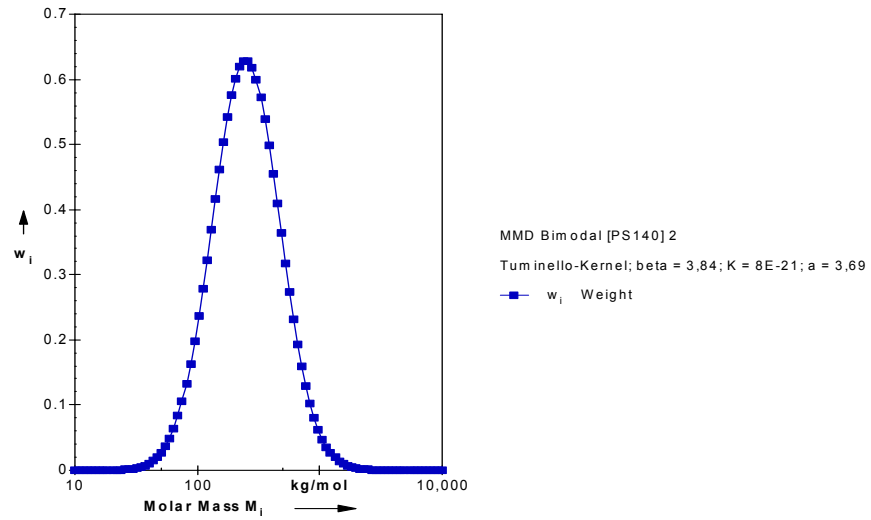


Fig. 13 - 5 MMD Bimodal $H(\lambda) \rightarrow w_i(M_i)$ - Example

13.3 MMD -> H(λ)

This method can be used to calculate the relaxation time spectrum from the molar mass distribution. The calculation uses the method of Baumgärtel, Schausberger and Winter and can be used for monodisperse pure polymers.

The screenshot shows a dialog box titled "MMD->H(λ)" with the following settings:

- Range of relaxation time λ , for which H(λ) will be calculated:**
 - Minimum: 1E-5 s
 - Maximum: 1E+5 s
 - Number: 100
- Use Temperature T in Input Data
- Material Parameters:**
 - Entanglement Molar Mass: 12,589 g/mol
 - Ent. Relax. Time λ_{e} : 5.62E-5 s
 - BSV Power-law Exponent: 0.23
 - Plateau Modulus G_{ND} : 213,796 Pa
 - CW Power-law Exponent: -0.67
 - CW Spectrum Parameter H_g : 134,896 Pa
- Result Variable: H(λ) sum
- Show Shift Factors
- Show Result Value Table

Buttons: OK, Cancel, Default, Info..

Fig. 13 - 6 MMD -> H(λ) - Parameter settings

13.3.1 Parameter Settings

Range

Enter the minimum and maximum relaxation time of the range for which you want the spectrum to be calculated.

Use Temperature T in Input Data

If this option is activated, the temperature values from the input data series are stored in the analysis result. This option requires, that the temperature is available in the input data series, otherwise an error message will be shown when the analysis is carried out.

Material Parameters

Enter the material parameters.

Use Temperature T in Input Data

If activated, the temperature values of the input data series are stored into the analysis result. This option should only be checked, if the input data contain the temperature, otherwise an error message will be shown.

Result Variable

Select whether to calculate the full spectrum, the entanglement spectrum or the glassy region.

Show Shift Factors

If this option is enabled, the shift factors are shown in the result field of the analysis window.

Show Result Value Table

With this option the input and output data points can be listed in the result window of the analysis window.

13.4 Molar Mass $\eta_0 \rightarrow M_w$

For polymer melts the average molar mass can be calculated from the zero shear viscosity according to the equations given below. For a number of materials the necessary coefficients are available from the material database. To access the database click the 'Material Database' button; then select the group and material at the appropriate temperature and click 'OK'. The material database is identical to that of the method 'MMD Kernels $H(\lambda) \rightarrow w_i(M_i)$ ' and is described in that chapter.

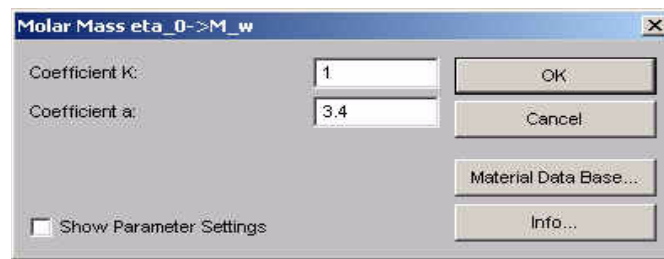


Fig. 13 - 7 Molar Mass $\eta_0 \rightarrow M_w$ - Parameter settings

$$\eta_0 = K \cdot (M_w)^a$$

$$M_w = \left(\frac{\eta_0}{K} \right)^{\frac{1}{a}}$$

η_0 - zero viscosity in [Pas]

K - coefficient

a - coefficient

M_w - molar mass in [g/mol]
(weight average)

The input data series for this analysis method has to contain the zero shear viscosity as a variable. This value has to be calculated by using 'Basic Arithmetic Operations' as a first step in the analysis. In the parameter settings for the basic arithmetic operations use e.g. the addition and add a value of zero. Apply the operation only to the viscosity and store the viscosity as a new variable, the zero shear viscosity. Use the result of this analysis as the input data for the calculation of the molar mass.

13.4.1 Parameter Settings

Coefficient K / Coefficient a

The coefficients are dependent on the material that is to be analysed. Enter the values or select a suitable entry from the material database.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

13.4.2 Example

The example below shows the measured viscosity curve of a polystyrene melt and the calculated average molar mass. The diagram further shows the curve fit of the Cross model and the calculated zero shear viscosity value.

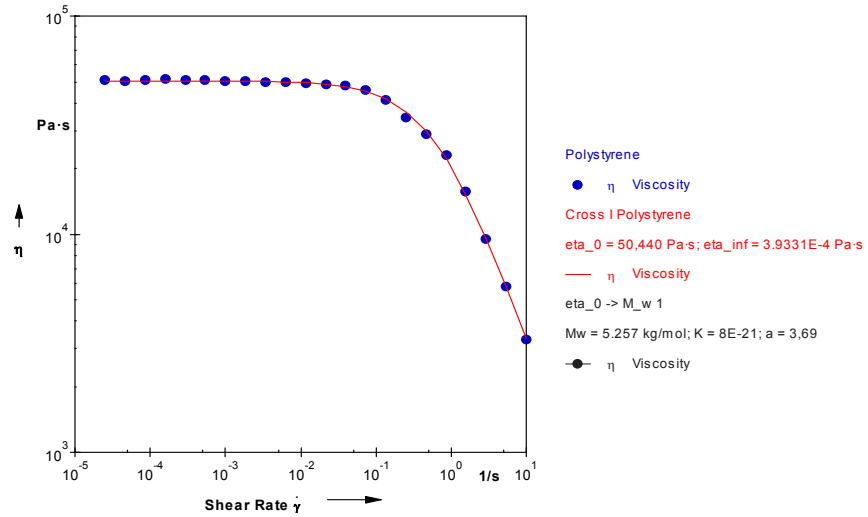


Fig. 13 - 8 Molar Mass $\eta_0 \rightarrow M_w$ - Example

13.5 Molar Mass $J_g \rightarrow M_w$

This method can be used to calculate the average molar mass of a polymer solution from the Staudinger index. The Staudinger index has to be known for this calculation and has to be available in the input data series. As input data series e.g. calculated or imported values can be used.

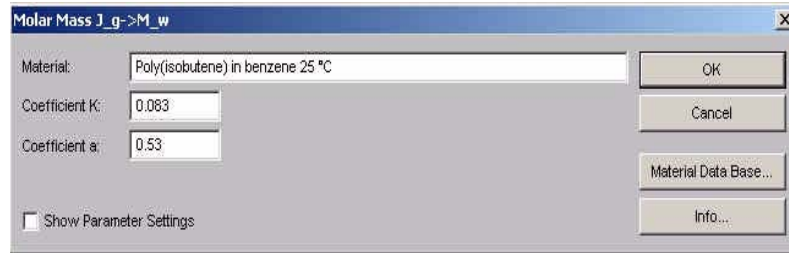


Fig. 13 - 9 Molar Mass $J_g \rightarrow M_w$ - Parameter settings

$$J_g = K \cdot (M_w)^a$$

$$M_w = \left(\frac{J_g}{K} \right)^{\frac{1}{a}}$$

J_g - Staudinger ind. in [cm³/g]
 K - coefficient
 a - coefficient
 M_w - molar mass in [g/mol]
 (weight average)

The coefficients can be entered manually if they are known. For a number of materials, the relevant coefficients are available in the material database accessible with the 'Material Database' button. Select the group and material in the lists, then click 'OK'. The coefficients are then shown in the parameter settings, where they can still be adjusted for a better fit if necessary.

13.5.1 Parameter Settings

Coefficient K / Coefficient a

The coefficients are dependent on the material that is to be analysed. Enter the values or select a suitable entry from the material database.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

13.5.2 Example

The diagram shows the viscosity curve of a polymer solution and the average molar mass calculated using the Staudinger index for this material.

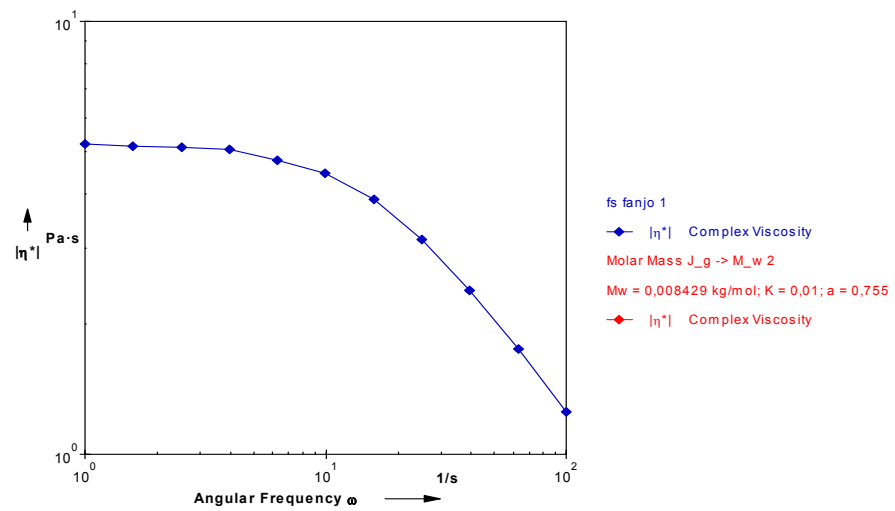


Fig. 13 - 10 Molar Mass $J_g \rightarrow M_w$ - Example

13.6 Molar Mass LCB Index

This method determines the LCB (long chain branching) index using the average molar weight calculated by the Carreau-Yasuda method and the average molar weight calculated from the crossover frequency. As input data a frequency sweep is required.

The method uses numerical values that are valid for isotactic polypropylene only.

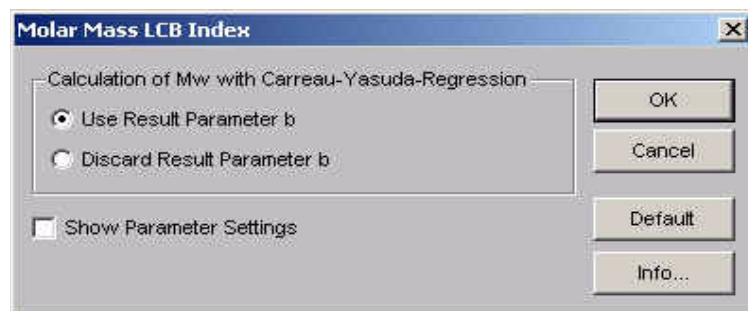


Fig. 13 - 11 Molar Mass LCD Index - Parameter settings

13.7 Molar Mass Mooney-Rivlin

This method calculates the average molar mass M_c , the concentration of crosslinking points X and the density of crosslinking n_i of solid elastomers according to Mooney-Rivlin. Information on the calculation can be found under 'Info'. The input data are the storage modulus G' and the temperature T .

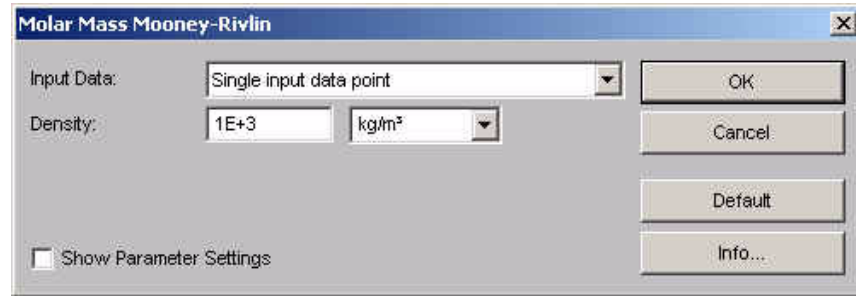


Fig. 13 - 12 Molar Mass Mooney-Rivlin - Parameter settings

13.8 Parameter Settings

Input Data

If 'Single input data point' is selected the values for storage modulus G' and temperature T from each selected data point are used. With the second option 'Mean value...' and average of all selected input data points is used.

Density

Enter the value for the sample density and select the appropriate unit.

Show Parameter Settings

If the option 'Show Parameter Settings' is checked the result field in the analysis window will include the selections that have been made for the parameter setup.

14 <Interfacial Rheology>

The analysis methods of this section can be used to evaluate data measured with the 'Interfacial Rheology System' (IRS).

14.1 Interfacial Viscosity

From rotational measurements with the interfacial rheology system only the raw data, i. e. torque M and rotational speed n , can be used. These have to be evaluated numerically to get the reduced torque and viscosity, as well as the interfacial shear stress and interfacial viscosity. The method 'Interfacial Viscosity' provides the necessary calculations for rotational measurements.

The screenshot shows a dialog box titled 'Interfacial Viscosity' with the following parameters and controls:

Height of Lower Fluid H1:	22.5	mm	<input type="button" value="OK"/> <input type="button" value="Cancel"/> <input type="button" value="Default"/> <input type="button" value="Info..."/>
Total Height of Both Fluids H1+H2:	45	mm	
Inner Radius of Measuring Cell R:	40	mm	
Bicone Radius Rms:	34.14	mm	
Bicone Angle theta:	5	°	
<input type="checkbox"/> Viscosity of Upper Fluid is Constant:			
<input type="checkbox"/> Viscosity of Lower Fluid is Constant:			
<input checked="" type="checkbox"/> Show Loop No. during Calculation			

Fig. 14 - 1 Interfacial Viscosity - Parameter settings

14.1.1 Parameter Settings

Height of Lower Fluid H1 / Total Height of Both Fluids H1+H2

Enter the filling height of the lower fluid and the total height of the sample. If only one fluid is measured, you can leave the default value for the total height.

Inner Radius of Measuring Cell R

Enter the radius of the sample cup.

Bicone Radius Rms / Bicone Angle theta

Enter the dimensions of the bicone measuring system. The values are given on the measuring system box.

Viscosity of Upper / Lower Fluid is Constant

Enable the option, if the viscosity of the relevant fluid is independent of the applied shear rate and enter the viscosity value (shear viscosity). If the viscosity is not constant, the method requires the viscosity curves of the lower and of the upper fluid as two additional input data series. The viscosity curve of the lower fluid needs to be the first, the viscosity curve of the upper fluid the second and the interfacial measurement the third input data series.

Show Loop No. during Calculation

If this option is enabled the number each data point of the interfacial data series is shown in the result field of the analysis while the point is processed.

14.1.2 Example

The diagram shows the result of a number of interfacial measurements with a surfactant on water and the calculated nomograph (from 'Interfacial Simulation').

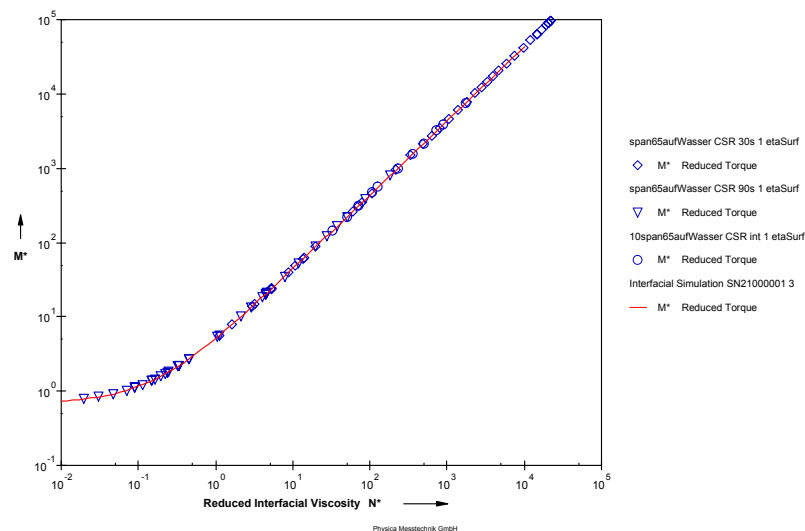


Fig. 14 - 2 Interfacial Viscosity - Example

14.2 Interfacial Oscillation

This method is used to calculate the complex interfacial viscosity from frequency sweep measurements. Depending on the parameter settings this method requires one or three input data curves (see 'Parameter settings').

The screenshot shows the 'Interfacial Oscillation' dialog box with the following settings:

- Geometry Data:**
 - Height of Lower Fluid H1: 22.5 mm
 - Total Height of Both Fluids H1+H2: 45 mm
 - Inner Radius of Measuring Cell R: 40 mm
 - Bicone Radius Rms: 34.14 mm
 - Bicone Angle theta: 5 °
- Upper Fluid:**
 - Density rho2: 1 g/cm³
 - Complex Viscosity $\eta_{a2} = \eta_{a2}' - i \cdot \eta_{a2}''$ is Constant:
 - Re(Viscosity) η_{a2}' : 1E-3 Pa·s
 - Im(Viscosity) η_{a2}'' : 1E-3 Pa·s
- Lower Fluid:**
 - Density rho1: 1 g/cm³
 - Complex Viscosity $\eta_{a1} = \eta_{a1}' - i \cdot \eta_{a1}''$ is Constant:
 - Re(Viscosity) η_{a1}' : 1E-3 Pa·s
 - Im(Viscosity) η_{a1}'' : 1E-3 Pa·s
- Show Loop No. during Calculation

Fig. 14 - 3 Interfacial Oscillation - Parameter settings

14.2.1 Parameter Settings

Height of Lower Fluid H1 / Total Height of Both Fluids H1+H2

Enter the filling height of the lower fluid and the total height of the sample. If only one fluid is measured, you can leave the default value for the total height.

Inner Radius of Measuring Cell R

Enter the radius of the sample cup.

Bicone Radius Rms / Bicone Angle theta

Enter the dimensions of the bicone measuring system. The values are given on the measuring system box.

Density rho2 / rho1

Enter the density of the upper and the lower fluid.

Complex Viscosity eta2 / eta1 is Constant

Enable the option, if the viscosity of the relevant fluid is independent of the frequency and enter the viscosity values for each fluid. If the viscosity is not constant, the method requires the frequency sweeps of the lower and of the upper fluid as two additional input data series. The frequency sweep of the lower fluid needs to be the first, the frequency sweep of the upper fluid the second and the interfacial measurement the third input data series.

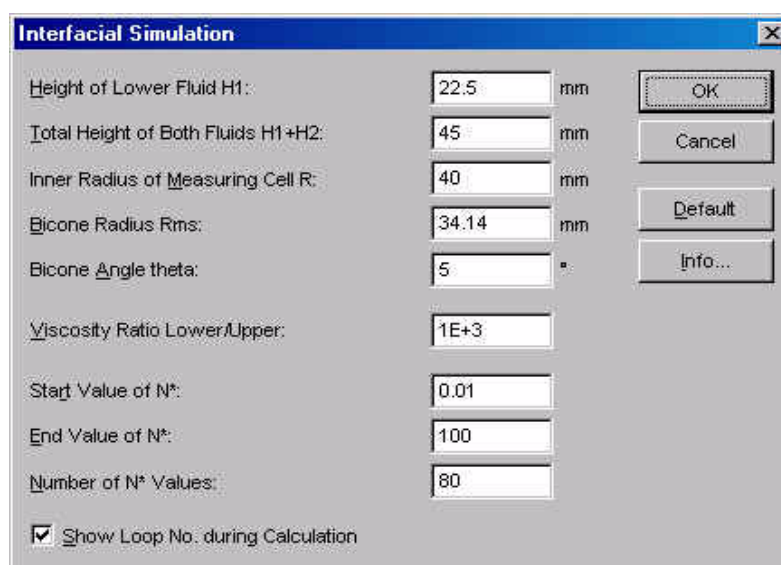
Show Loop No. during Calculation

If this option is enabled the number each data point of the interfacial data series is shown in the result field of the analysis while the point is processed.

14.3 Interfacial Simulation

The method 'Interfacial Simulation' can be used to calculate the group of curves for the reduced torque as a function of the reduced interfacial viscosity. The data are dependent on the geometry of the measuring system, namely the ratio of the radii of the measuring system and the measuring cell, and the ratio of the viscosity values of both fluids.

The analysis method does not require an input data series. Please note that the algorithm may not be able to calculate all required points for all ranges of N^* and viscosity ratios. In that case an error message is shown and the resulting curve will not be continuous; but it can still be used.



The screenshot shows a dialog box titled "Interfacial Simulation" with the following parameters and controls:

Parameter	Value	Unit
Height of Lower Fluid H1:	22.5	mm
Total Height of Both Fluids H1+H2:	45	mm
Inner Radius of Measuring Cell R:	40	mm
Bicone Radius Rms:	34.14	mm
Bicone Angle theta:	5	°
Viscosity Ratio Lower/Upper:	1E+3	
Start Value of N^* :	0.01	
End Value of N^* :	100	
Number of N^* Values:	80	

Additional controls on the right side of the dialog box include buttons for "OK", "Cancel", "Default", and "Info...". At the bottom left, there is a checked checkbox labeled "Show Loop No. during Calculation".

Fig. 14 - 4 Interfacial Simulation - Parameter settings

14.3.1 Parameter Settings

To calculate the group of curves enter height of the lower fluid, the total height of both fluids and the dimensions of measuring system and measuring cell. Further, you need to enter the ratio of the viscosity values of both fluids and the range of N^* for which the curves should be calculated. The viscosity ratio should not exceed 1000, values higher than this will be limited to 1000.

14.3.2 Example

The example shows a group of curves for the system from the previous figure. The curves for several viscosity ratios have been calculated.

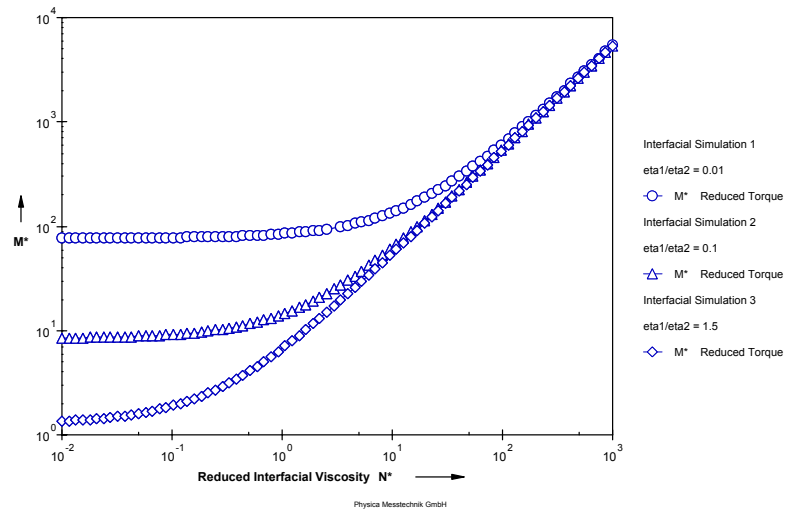


Fig. 14 - 5 Interfacial Simulation - Example

All measured curves with a given viscosity ratio will fit on the calculated curve with the same viscosity ratio. Therefore, the results of the simulation can be used as a nomograph.

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