SD01151D/06/EN/01.13
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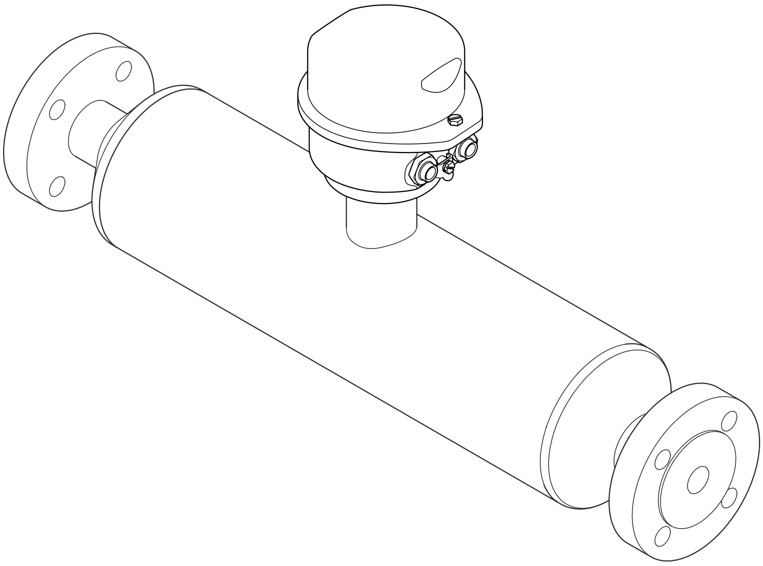
Special Documentation
Proline Promass I 100

Viscosity Measurement Application Package



Endress+Hauser
People for Process Automation

1 Document information

1.1 Document function

The document is part of the Operating Instructions and serves as a reference for application-specific parameters, providing a detailed explanation of each individual parameter of the operating menu.

1.2 Using this document

1.2.1 Information on the document structure

For the alignment of parameters with short descriptions according to the **Display/ Operation**, **Setup**, **Diagnostics** menu structure, Operating Instructions manual for the device.

For information about the operating philosophy, see the "Operating philosophy" chapter in the device's Operating Instructions

1.3 Symbols used

1.3.1 Symbols for certain types of information

Symbol	Meaning
A0011193	**Tip** Indicates additional information.
A0011194	**Reference to documentation** Refers to the corresponding device documentation.
A0011195	**Reference to page** Refers to the corresponding page number.
A0011196	**Reference to graphic** Refers to the corresponding graphic number and page number.
A0013140	**Operation via local display** Indicates navigation to the parameter via the local display.
A0013143	**Operation via operating tool** Indicates navigation to the parameter via the operating tool.
A0013144	**Write-protected parameter** Indicates a parameter that can be locked against changes by entering a user-specific code.

1.3.2 Symbols in graphics

Symbol	Meaning
1, 2, 3 ...	Item numbers
A, B, C, ...	Views
A-A, B-B, C-C, ...	Sections

1.4 Documentation

This manual is a Special Documentation; it does not replace the Operating Instructions included in the scope of supply.

For detailed information, refer to the Operating Instructions and other documentation on the CD-ROM provided or visit "www.endress.com/deviceviewer".

The Special Documentation is an integral part of the following Operating Instructions:

Modbus RS485	EtherNet/IP	HART
BA01058D	BA01066D	BA01190D

This Special Documentation is available:
- On the CD-ROM supplied with the device (depending on the device version ordered)
- In the Download Area of the Endress+Hauser Internet site: www.endress.com → Download

1.4.1 Content and scope

This Special Documentation contains a description of the additional parameters and technical data that are provided with the Viscosity application package. All the parameters that are not relevant to viscosity measurement are described in the Operating Instructions.

General information on viscosity and viscosity measurement can be found in the "Viscosity fundamentals" section.

2 Commissioning

2.1 Availability

If the optional package for **Viscosity measurement** was ordered for the flowmeter from the factory, the function is already available when the measuring device is delivered to the customer. The function is accessed via the operating interfaces of the measuring device, via the Web server or Endress+Hauser's FieldCare asset management software. No particular measures are required to put the function into operation.

Ways to check function availability in the measuring device:
- Using the serial number:
  W@M Device viewer [1] → Order code option **EG** "Viscosity measurement"
- In the operating menu:
  Check whether the function is indicated in the operating menu: Diagnostics → Measured values → Process variables → Viscosity
  If the "Viscosity" option is available the function is activated.

If the function cannot be accessed in the measuring device, the optional package was not selected. It is then possible to upgrade to this function during the life cycle of the measuring device. On most flowmeters it is possible to activate the function without having to upgrade the firmware.

2.1.1 Activation without firmware upgrade

Retrofitting the viscosity option in the life cycle, requires a of viscosity calibration. It is therefore essential to return the instrument to Endress+Hauser.

Activation without firmware upgrade is possible as of the following firmware versions:
- Modbus RS485: 01.02.zz
- EtherNet/IP: 01.01.zz
- HART: 01.00.zz
- PROFIBUS DP: 01.00.zz

2.1.2 Firmware upgrade before activation

If you have a measuring device that requires a firmware upgrade before the function can be activated, please contact your Endress+Hauser service organization.

This function requires service-level access to the device.

A firmware upgrade is required for measuring devices with earlier firmware versions (see "2.1.1 Activation without firmware upgrade"). In addition the reference condition of the sensor must be recorded and selected during commissioning.

Please contact your Endress+Hauser service or sales organization for further information regarding product availability and upgrades to existing measuring devices.

2.2 4-20 mA HART communication method

2.2.1 Configuring the measuring device

The description in this section applies to the following communication method: 4-20 mA HART

1) www.endress.com/deviceviewer

Configuring the current output

Setup	→	**...**	→	
		Current output 1	→	...
				Assign current output

Parameter	Description	Selection/ User entry	Factory setting
Assign current output	Select process variable for current output.	▪ ... ▪ Dynamic viscosity ▪ Kinematic viscosity ▪ Temperature compensated dynamic viscosity ▪ Temperature compensated kinematic viscosity ▪ ...	Mass flow

Configuring the pulse/frequency/switch output

Setup	→	**...**	→	
		Pulse/frequency/switch output	→	...
				Assign frequency output
				...
				Assign limit

Parameter	Description	Selection/ User entry	Factory setting
Assign frequency output	Select the process variable for the frequency output.	▪ ... ▪ Dynamic viscosity ▪ Kinematic viscosity ▪ Temperature compensated dynamic viscosity ▪ Temperature compensated kinematic viscosity ▪ ...	Off
Assign limit	Select the process variable for the limit function.	▪ ... ▪ Dynamic viscosity ▪ Kinematic viscosity ▪ Temperature compensated dynamic viscosity ▪ Temperature compensated kinematic viscosity ▪ ...	Mass flow

Configuring the output conditioning

Setup	→	**...**		
		Output conditioning	→	...
				Assign current output
				...
				Assign frequency output

Parameter	Description	Selection/ User entry	Factory setting
Assign current output	Select process variable for current output.	■ ... ■ Dynamic viscosity ■ Kinematic viscosity ■ Temperature compensated dynamic viscosity ■ Temperature compensated kinematic viscosity ■ ...	Mass flow
Assign frequency output	Select process variable for frequency output.	■ ... ■ Dynamic viscosity ■ Kinematic viscosity ■ Temperature compensated dynamic viscosity ■ Temperature compensated kinematic viscosity ■ ...	Off

2.2.2 Advanced settings

Advanced setup	→	**...**		
		Viscosity	→	**Temperature compensation**
			→	**Dynamic viscosity**
			→	**Kinematic viscosity**

Temperature compensation

Structure of the submenu

Temperature compensation	→	
		Calculation model
		Reference temperature

	Compensation coefficient X1…X2	

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Calculation model	Use this function to select a calculation model (→ 🗎 27) for temperature compensation. Depending on the temperature behavior of the fluid, you can select the model that best represents the function.	▪ Power law ▪ Exponential ▪ Polynomial	Polynomial
Reference temperature	Use this function to enter the reference temperature for calculating the temperature-compensated viscosity	Floating-point number with sign	0 °C
Compensation coefficient X1…X2	Use this function to enter the compensation coefficient for calculating the temperature-compensated viscosity. Calculation: (→ 🗎 27))	Floating-point number with sign	0

Dynamic viscosity

Structure of the submenu

Dynamic viscosity	→	
		Dynamic viscosity unit
		User dynamic viscosity text
		User dynamic viscosity factor
		User dynamic viscosity offset

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Dynamic viscosity unit	Select the unit for dynamic viscosity.	Country-specific: ▪ Pa s ▪ mPa s ▪ P ▪ cP ▪ User-defined	cP
User dynamic viscosity text	Use this function to enter a text for the user-defined unit. You only define the text, the unit of time is provided from a choice of options (s, min, h, day).	Max. 10 characters such as letters, numbers or special characters (+, -, underscore, space)	UserDynVis
User dynamic viscosity factor	Use this function to enter the quantity factor for the user-defined unit. This factor refers to a dynamic viscosity of 1 m^2/s .	Floating-point number with sign	1
User dynamic viscosity offset	Use this function to enter an offset for the measured value for dynamic viscosity. The offset is added or subtracted, depending on the sign.	Floating-point number with sign	0

Kinematic viscosity

Structure of the submenu

Kinematic viscosity	→	
		Kinematic viscosity unit
		User kinematic viscosity text
		User kinematic viscosity factor
		User kinematic viscosity offset

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Kinematic viscosity unit	Select the unit for kinematic viscosity.	Country-specific: ▪ m^2/s ▪ mm^2/s ▪ St ▪ cSt ▪ User-defined	cSt
User kinematic viscosity text	Use this function to enter a text for the user-defined unit. You only define the text, the unit of time is provided from a choice of options (s, min, h, day).	Max. 10 characters such as letters, numbers or special characters (+, -, underscore, space)	UserKinVis
User kinematic viscosity factor	Use this function to enter the quantity factor for the user-defined unit. This factor refers to a kinematic viscosity of 1 m^2/s .	Floating-point number with sign	1
User kinematic viscosity offset	Use this function to enter an offset for the measured value for kinematic viscosity. The offset is added or subtracted, depending on the sign.	Floating-point number with sign	0

2.2.3 Simulation

Diagnostics	→	**...**		
		Simulation	→	Assign simulation process variable

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Assign simulation process variable	Select a process variable for the simulation process that is activated.	▪ ... ▪ Dynamic viscosity ▪ Kinematic viscosity ▪ Temp. compensated dynamic viscosity ▪ Temp. compensated kinematic viscosity ▪ ...	Off

2.3 EtherNet/IP communication method

2.3.1 Advanced settings

Advanced setup	→	**...**		
		Viscosity	→	**Temperature compensation**
			→	**Dynamic viscosity**
			→	**Kinematic viscosity**

Temperature compensation

Structure of the submenu

Temperature compensation	→	
		Calculation model
		Reference temperature
		Compensation coefficient X1...X2

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Calculation model	Use this function to select a calculation model (→ 🗎 27) for temperature compensation. Depending on the temperature behavior of the fluid, you can select the model that best represents the function.	▪ Power law ▪ Exponential ▪ Polynomial	Polynomial
Reference temperature	Use this function to enter the reference temperature for calculating the temperature-compensated viscosity	Floating-point number with sign	0 °C
Compensation coefficient X1...X2	Use this function to enter the compensation coefficient for calculating the temperature-compensated viscosity. Calculation: (→ 🗎 27))	Floating-point number with sign	0

Dynamic viscosity

Structure of the submenu

Dynamic viscosity	→	
		Dynamic viscosity unit
		User dynamic viscosity text
		User dynamic viscosity factor

	User dynamic viscosity offset	

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Dynamic viscosity unit	Select the unit for dynamic viscosity.	Country-specific: ▪ Pa s ▪ mPa s ▪ P ▪ cP ▪ User-defined	cP
User dynamic viscosity text	Use this function to enter a text for the user-defined unit. You only define the text, the unit of time is provided from a choice of options (s, min, h, day).	Max. 10 characters such as letters, numbers or special characters (+, -, underscore, space)	UserDynVis
User dynamic viscosity factor	Use this function to enter the quantity factor for the user-defined unit. This factor refers to a dynamic viscosity of 1 m^2/s .	Floating-point number with sign	1
User dynamic viscosity offset	Use this function to enter an offset for the measured value for dynamic viscosity. The offset is added or subtracted, depending on the sign.	Floating-point number with sign	0

Kinematic viscosity

Structure of the submenu

Kinematic viscosity →		
	Kinematic viscosity unit	
	User kinematic viscosity text	
	User kinematic viscosity factor	
	User kinematic viscosity offset	

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Kinematic viscosity unit	Select the unit for kinematic viscosity.	Country-specific: ▪ m^2/s ▪ mm^2/s ▪ St ▪ cSt ▪ User-defined	cSt
User kinematic viscosity text	Use this function to enter a text for the user-defined unit. You only define the text, the unit of time is provided from a choice of options (s, min, h, day).	Max. 10 characters such as letters, numbers or special characters (+, -, underscore, space)	UserKinVis

Parameter	Description	Selection/input	Factory settings
User kinematic viscosity factor	Use this function to enter the quantity factor for the user-defined unit. This factor refers to a kinematic viscosity of 1 m^2/s .	Floating-point number with sign	1
User kinematic viscosity offset	Use this function to enter an offset for the measured value for kinematic viscosity. The offset is added or subtracted, depending on the sign.	Floating-point number with sign	0

2.3.2 Simulation

Diagnostics	→	**...**		
		Simulation	→	Assign simulation process variable

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Assign simulation process variable	Select a process variable for the simulation process that is activated.	▪ ... ▪ Dynamic viscosity ▪ Kinematic viscosity ▪ Temp. compensated dynamic viscosity ▪ Temp. compensated kinematic viscosity ▪ ...	Off

2.4 Modbus RS485 communication method

2.4.1 Advanced settings

Advanced setup → **...**

Viscosity → **Temperature compensation**

→ **Dynamic viscosity**

→ **Kinematic viscosity**

Temperature compensation

Structure of the submenu

Temperature compensation →

Calculation model

Reference temperature

Compensation coefficient X1...X2

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Calculation model Modbus register: 9401 Data type: integer Access: read/write	Use this function to select a calculation model (→ 📄 27) for temperature compensation. Depending on the temperature behavior of the fluid, you can select the model that best represents the function.	0 = polynomial 1 = power law 2 = exponential	Polynomial
Reference temperature Modbus register: 9402 Data type: integer Access: read/write	Use this function to enter the reference temperature for calculating the temperature-compensated viscosity	Floating-point number with sign	0 °C
Compensation coefficient X1...X2 Modbus register X1: 9404 Modbus register X2: 9406 Data type: integer Access: read/write	Use this function to enter the compensation coefficient for calculating the temperature-compensated viscosity. Calculation: (→ 📄 27))	Floating-point number with sign	0

Dynamic viscosity

Structure of the submenu

Dynamic viscosity →

Dynamic viscosity unit
User dynamic viscosity text
User dynamic viscosity factor
User dynamic viscosity offset

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Dynamic viscosity unit Modbus register: 2111 Data type: integer Access: read/write	Select the unit for dynamic viscosity.	Country-specific: 0 = cP 1 = P 2 = Pa s 3 = mPa s 4 = user-defined	0 = cP
User dynamic viscosity text Modbus register: 3353 Data type: string Access: read/write	Use this function to enter a text for the user-defined unit. You only define the text, the unit of time is provided from a choice of options (s, min, h, day).	Max. 10 characters such as letters, numbers or special characters (+, -, underscore, space)	UserDynVis
User dynamic viscosity factor Modbus register: 2137 Data type: float Access: read/write	Use this function to enter the quantity factor for the user-defined unit. This factor refers to a dynamic viscosity of 1 m^2/s .	Floating-point number with sign	1
User dynamic viscosity offset Modbus register: 2139 Data type: float Access: read/write	Use this function to enter an offset for the measured value for dynamic viscosity. The offset is added or subtracted, depending on the sign.	Floating-point number with sign	0

Kinematic viscosity

Structure of the submenu

Kinematic viscosity →	
	Kinematic viscosity unit
	User kinematic viscosity text
	User kinematic viscosity factor
	User kinematic viscosity offset

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Kinematic viscosity unit Modbus register: 2112 Data type: integer Access: read/write	Select the unit for kinematic viscosity.	Country-specific: 0 = m^2/s 1 = mm^2/s 2 = cSt 3 = St 4 = user-defined	2 = cSt
User kinematic viscosity text Modbus register: 3358 Data type: string Access: read/write	Use this function to enter a text for the user-defined unit. You only define the text, the unit of time is provided from a choice of options (s, min, h, day).	Max. 10 characters such as letters, numbers or special characters (+, -, underscore, space)	UserKinVis
User kinematic viscosity factor Modbus register: 2143 Data type: float Access: read/write	Use this function to enter the quantity factor for the user-defined unit. This factor refers to a kinematic viscosity of 1 m^2/s .	Floating-point number with sign	1
User kinematic viscosity offset Modbus register: 2145 Data type: float Access: read/write	Use this function to enter an offset for the measured value for kinematic viscosity. The offset is added or subtracted, depending on the sign.	Floating-point number with sign	0

2.4.2 Simulation

Diagnostics → **...**

Simulation → Assign simulation process variable

Parameter overview with brief description

Parameter	Description	Selection/input	Factory settings
Assign simulation process variable Modbus register: 6813 Data type: integer Access: read/write	Select a process variable for the simulation process that is activated.	... 45 = kinematic viscosity 46 = dynamic viscosity 76 = temp. compensated dynamic viscosity 77 = temp. compensated kinematic viscosity ...	Off

3 Operation

3.1 4-20 mA HART and EtherNet/IP communication method

3.1.1 Reading off measured values

Diagnostics	→	**...**		
		Measured values	→	**Process variables**

Parameter overview with brief description

Parameter	Description	Display
Dynamic viscosity	Displays the dynamic viscosity currently calculated	Floating-point number with sign
Kinematic viscosity	Displays the kinematic viscosity currently calculated	Floating-point number with sign
Temperature compensated dynamic viscosity	Displays the temperature-compensated dynamic viscosity currently calculated	Floating-point number with sign
Temperature compensated kinematic viscosity	Displays the temperature-compensated kinematic viscosity currently calculated	Floating-point number with sign

3.2 Modbus RS485 communication method

3.2.1 Reading off measured values

Diagnostics	→	**...**		
		Measured values	→	**Process variables**

Parameter overview with brief description

Parameter	Description	Display
Dynamic viscosity Modbus register: 2019 Data type: float Access: read	Displays the dynamic viscosity currently calculated	Floating-point number with sign
Kinematic viscosity Modbus register: 2083 Data type: float Access: read	Displays the kinematic viscosity currently calculated	Floating-point number with sign
Temperature compensated dynamic viscosity Modbus register: 2093 Data type: float Access: read	Displays the temperature-compensated dynamic viscosity currently calculated	Floating-point number with sign
Temperature compensated kinematic viscosity Modbus register: 2095 Data type: float Access: read	Displays the temperature-compensated kinematic viscosity currently calculated	Floating-point number with sign

4 Technical data

4.1 Application

(→ 📄 3)

4.2 Input

4.2.1 Measuring range

DN		Viscosity measurement in non-hazardous area	Viscosity measurement in hazardous area
[mm]	[in]		
8	³⁄₈	5600 mPa·s	5600 mPa·s
15	½	10300 mPa·s	10300 mPa·s
25	1	20000 mPa·s	20000 Pa·s
40	1½	20000 mPa·s	5500 Pa·s (20000 mPa·s)
50	2	20000 mPa·s	5200 Pa·s (20000 mPa·s)
80	3	20000 mPa·s	2700 Pa·s (14100 mPa·s)

4.3 Output

Extended options if the viscosity application package is used

4.3.1 Output signal

Current output

Assignable measured variables	▪ … ▪ Dynamic viscosity ▪ Kinematic viscosity ▪ Temp. compensated dynamic viscosity ▪ Temp. compensated kinematic viscosity ▪ …

Pulse/frequency/switch output

Frequency output

Assignable measured variables	▪ … ▪ Dynamic viscosity ▪ Kinematic viscosity ▪ Temp. compensated dynamic viscosity ▪ Temp. compensated kinematic viscosity ▪ …

Switch output

Assignable functions	▪ … ▪ Limit value – … – Dynamic viscosity – Kinematic viscosity – Temp. compensated dynamic viscosity – Temp. compensated kinematic viscosity – …

4.3.2 Protocol-specific data

HART

Dynamic variables	The measured variables can be freely assigned to the dynamic variables. **Measured variables for SV, TV, QV (secondary, tertiary and quaternary dynamic variable)** ▪ … ▪ Dynamic viscosity ▪ Kinematic viscosity ▪ Temp. compensated dynamic viscosity ▪ Temp. compensated kinematic viscosity ▪ …

EtherNet/IP

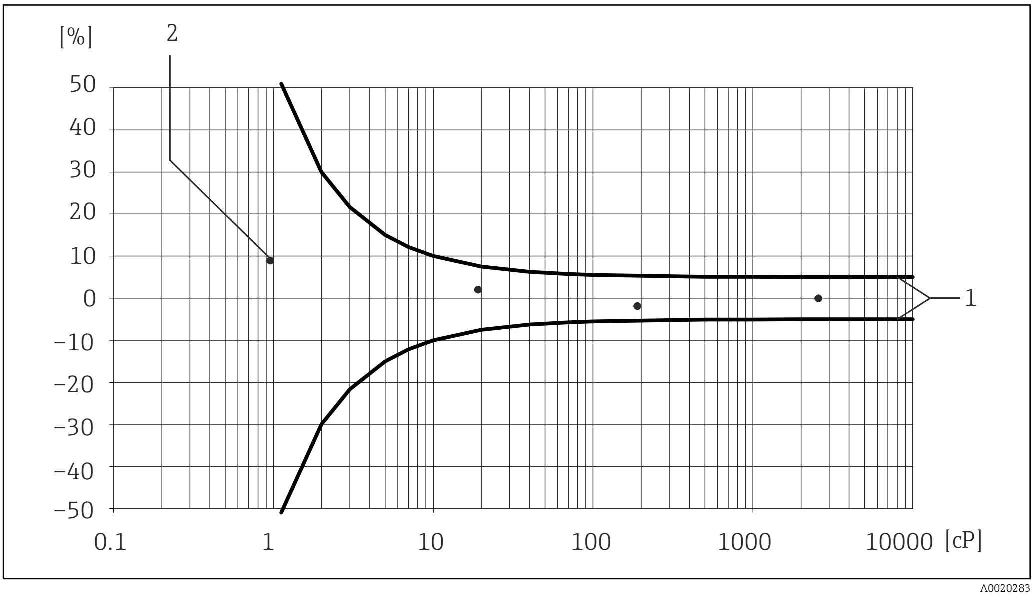
Configurable Input

Configurable Input Assembly	▪ … ▪ Dynamic viscosity ▪ Kinematic viscosity ▪ Temp. compensated dynamic viscosity ▪ Temp. compensated kinematic viscosity ▪ …

4.4 Performance characteristics

4.4.1 Maximum measured error

Accuracy for Newtonian liquids	±5% ± 0.5 mPa·s (c·P) of reading



1 Error diagram with information on the relative error in % for the behavior of a dynamic viscosity in mPa·s

1 Maximum measured error
2 Typical measuring points of viscosity calibration

4.4.2 Repeatability

±0.5% of reading

5 Viscosity fundamentals

Viscosity describes the flow properties of fluids (liquid and gas). This property depends on forces acting between the molecules. The more viscous a fluid, the stronger these intermolecular forces. As a result, a larger internal resistance has to be overcome to move through the fluid or apply a force to it.

5.1 Definitions of viscosity (general)

Consider a liquid between two parallel plates. If you slide one of the plates parallel against the other in a horizontal direction(→ 2, 20) a certain force F (shear force) is needed as the liquid acts against the flow movement in the form of an internal resistance.

The relationship between the moving surface A and the shear force F is known as shear stress τ.

$$\tau = \frac{F}{A} \qquad Pa \quad \frac{N}{m^2}$$

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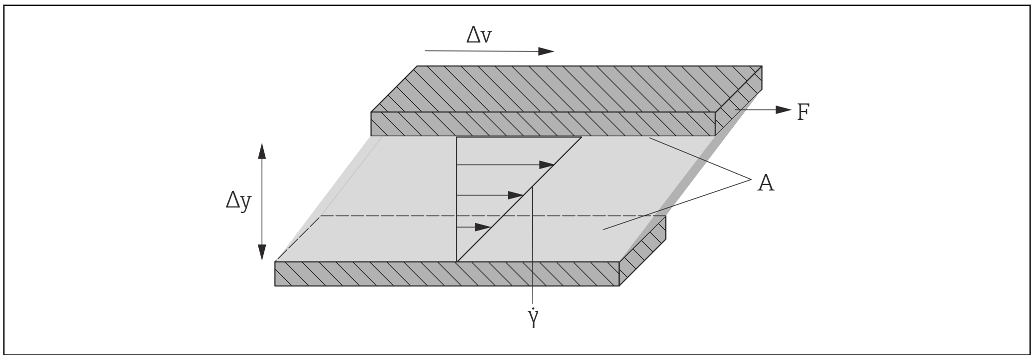

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2 *Shear rate*

A	Friction surface
F	Shear force
γ̇	Shear rate
Δv	Change in velocity
Δy	Plate distance or layer thickness

The relationship between the change in velocity Δv and layer thickness Δy (distance between the plates) is known as the shear rate $\dot{\gamma}$.

$$\dot{\gamma} = \frac{\Delta y}{\Delta v} \qquad \frac{m}{m \cdot s} = \frac{1}{s}$$

A0019948

5.1.1 Dynamic viscosity

The dynamic viscosity (η) is calculated from the ratio of the shear stress τ to the shear rate $\dot{\gamma}$.

$$\eta = \frac{\tau}{\dot{\gamma}} = \frac{F/A}{\Delta v / \Delta y} = \frac{F \cdot \Delta y}{A \cdot \Delta v} \qquad \frac{N/m^2}{(m/s)/m} = \frac{N \cdot m}{(m/s) \cdot m^2} = \frac{N \cdot s}{m^2} = Pa \cdot s$$

A0019947

The SI unit for dynamic viscosity η is the pascal second (Pa · s). The poise (P) unit is also widely used, where:

1 mPa · s = 1 cP

1 Pa · s = 10 P

A selection of the most common viscosity units: (→ 28).

5.1.2 Kinematic viscosity

The kinematic viscosity ν is the quotient from the dynamic viscosity η of the liquid and its density ρ.

$$\nu = \frac{\eta}{\rho} \qquad \frac{(N \cdot s)/m^2}{kg/m^3} = \frac{(kg \cdot m/s^2 \cdot s)/m^2}{kg/m^3} = \frac{m^2}{s}$$

A0019950

The SI unit of kinematic viscosity is m^2/s. The stokes (St) unit is also widely used, where:

1 m^2/s = 1 000 000 cSt

1 mm^2/s = 1 cSt (centistokes)

A selection of the most common viscosity units: (→ 28).

5.2 Differentiating viscous behavior

A distinction is made between Newtonian liquids and non-Newtonian liquids based on their viscosity behavior at different shear rates. In Newtonian liquids, the viscosity behavior remains constant at different shear rates. In non-Newtonian liquids, the viscosity behavior changes at different shear rates.

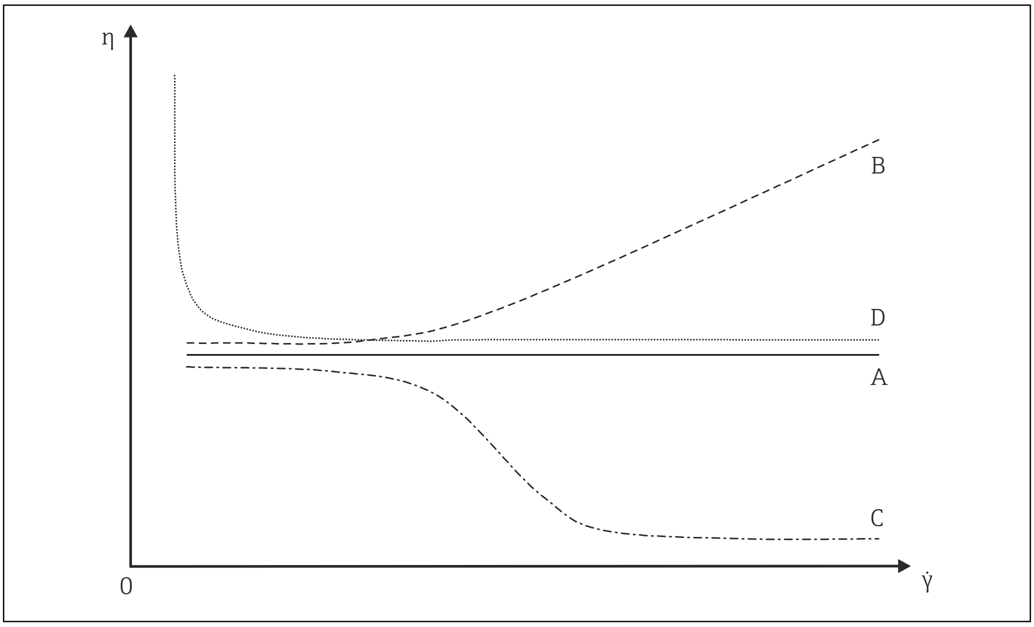
5.2.1 Newtonian liquids

	Example	Viscosity behavior with increasing shear rate
Feature	▪ Water ▪ Lube oils	No effect

5.2.2 Non-Newtonian liquids

		Example	Viscosity behavior with increasing shear rate
Time-independent behavior	**Dilatant Liquid**	▪ Concentrated solutions of sugar and water ▪ Aqueous suspensions of rice starch ▪ Wet sand	Increases
	Pseudoplastic liquid	▪ Gelatine ▪ Clay ▪ Milk ▪ Cream ▪ Fruit juice concentrate ▪ Salad dressings	Increases
	Bingham-plastic liquid	▪ Certain emulsions ▪ Oil paint	Decreases but acts like a Newtonian liquid as of a certain shear rate
Time-dependent behavior	**Thixothropic liquid**	▪ Yogurt ▪ Mayonnaise ▪ Margarine ▪ Ice cream ▪ Paints	Decreases but assumes the original state when in quiescent state
	Rheopectic liquid	▪ Gypsum in water ▪ Printer ink	Increases but drops again when in quiescent state

5.2.3 Viscosity and flow curves



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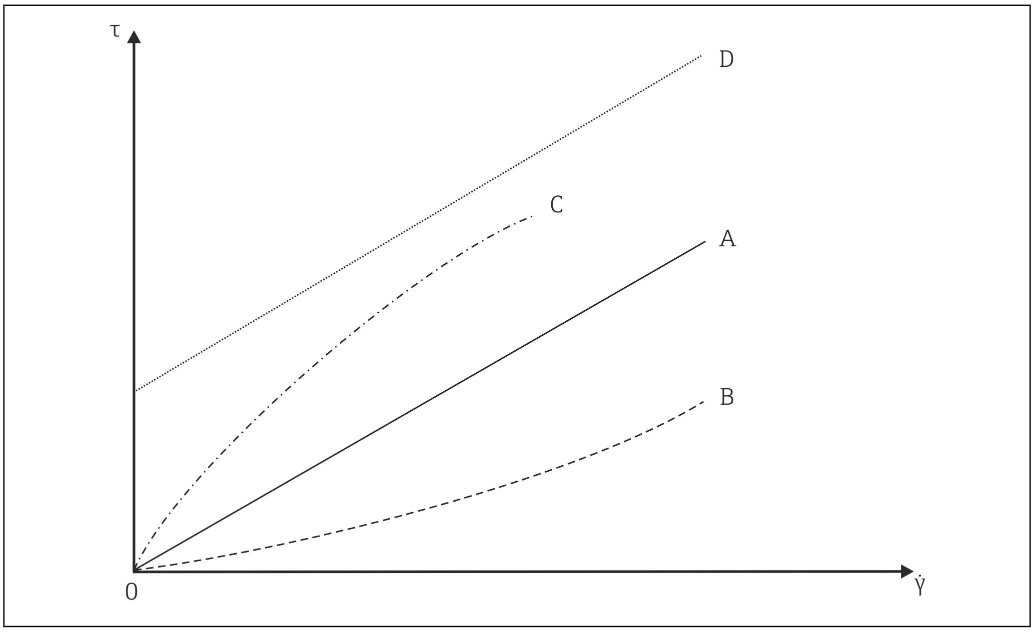
3 *Viscosity curves*

A	Viscosity curve of a Newtonian liquid
B	Viscosity curve of a dilatant liquid
C	Viscosity curve of a pseudoplastic liquid
D	Viscosity curve of a Bingham-plastic liquid
$\dot{\gamma}$	Shear rate
η	Dynamic viscosity

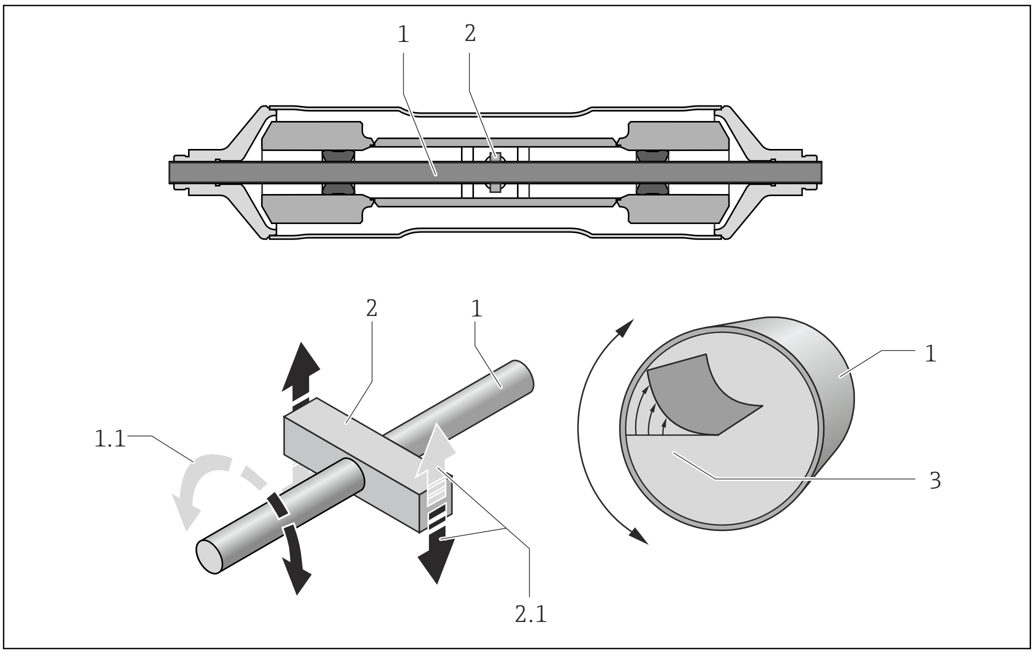


4 *Flow curves*

A	Flow curve of a Newtonian liquid
B	Flow curve of a dilatant liquid
C	Flow curve of a pseudoplastic liquid
D	Flow curve of a Bingham-plastic liquid
$\dot{\gamma}$	Shear rate
τ	Shear stress

5.3 Principle of viscosity measurement with Promass I

The patented measuring principle is based on torsional movement of the measuring tube:



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1 Measuring tube
1.1 Rotational movement of the measuring tube
2 Torsion bar
2.1 Rotational movement of the torsion bar
3 Velocity profile in the medium

A "torsion bar" (2) fitted to the measuring tube (1) imposes a rotational movement (torsional movement) which is used to measure the viscosity of the fluid. This torsional movement creates a velocity profile in the fluid (3) across the pipe cross-section. The velocity profile is thus an expression of the fluid viscosity. The viscosity of the fluid dampens the oscillation of the measuring tube so if viscosity is high, more excitation power (force, in other words) is needed to sustain the torsional movement. Thus, dynamic viscosity is determined by measuring the required excitation power. Fluid density is measured independently and simultaneously, so the kinematic viscosity can be determined as well.

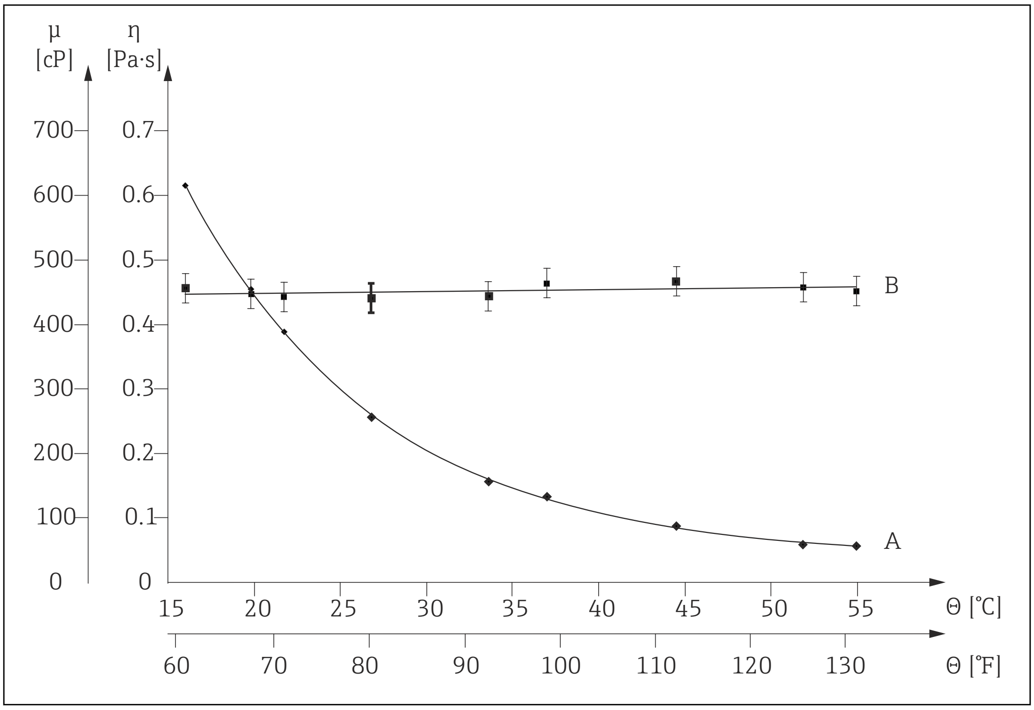
5.4 Temperature correction of the viscosity value

The viscosity of a liquid depends on the fluid temperature. Usually, the viscosity decreases with increasing temperatures.

The temperature effect becomes clear when laboratory and process measurements are compared. The process and laboratory temperatures normally deviate from one another. To be able to compare both measurements, the measuring device can calculate the process viscosity back to a reference temperature using various models. Three calculation models are available for this purpose (→ 27). The model selected should be the one for which the viscosity behavior has the lowest error deviations (→ 5, 26).

The device calculates the temperature correction of the viscosity value based on the compensation coefficients X1 and X2 (→ 6).

The following example illustrates the correction of the viscosity to 20 °C:



5 *Temperature correction of viscosity of glycerin to 20 °C*

μ, η	Dynamic viscosity
θ	Temperature
A	Measured value under process conditions
B	Calculated standard viscosity referenced to 20°C

5.5 Formula models for temperature correction

The measuring device calculates the temperature correction of the viscosity value on the basis of the following formulas:

Models	Dynamic viscosity η
Power law	$\eta_N = \eta \cdot x_1 \cdot (\theta/\theta_{ref})^{x_2}$
Exponential	$\eta_N = \eta \cdot x_1 \cdot e^{x_2 \cdot (\theta - \theta ref)}$
Polynomial	$\eta_N = \eta \cdot [1 + x_1 \cdot (\theta - \theta_{ref}) + x_2 \cdot (\theta - \theta_{ref})^2$

Models	Kinematic viscosity η
General	$v_N = \eta_N / \rho_N$

η_N	Dynamic viscosity under standard/laboratory conditions
η	Dynamic viscosity at process temperature
x_1	Compensation coefficient X_1
x_2	Compensation coefficient X_2
θ	Process temperature
θref	Reference temperature
v_N	Kinematic viscosity under standard/laboratory conditions
ρ_N	Reference density

- In the event of large temperature differences between the liquid and the environment, pipe heating or insulation can help avoid cooling effects of the liquid.
- If more than one liquid should be measured with temperature correction the calculation should take place externally (e.g. in a PLC).

6 Comparison tables for viscosities

Centipoise (cP) (mPa · s) 1)	Poise (P)	DIN cup 4 (s) 2)	Pascal second (Pa · s) 3)	°Engler	Ford cup 4 (s) 2)
10	0.1	10	0.01	1.83	5
15	0.15	11	0.015	2.32	8
20	0.2	12	0.02	2.87	10
25	0.25	13	0.025	3.46	12
30	0.3	14	0.03	4.07	14
40	0.4	15	0.04	5.33	18
50	0.5	16	0.05	6.62	22
60	0.6	18	0.06	7.93	25
70	0.7	21	0.07	9.23	28
80	0.8	23	0.08	10.54	32
90	0.9	25	0.09	11.86	34
100	1	27	0.1	13.17	37
120	1.2	31	0.12	15.8	43
140	1.4	34	0.14	18.43	48
160	1.6	38	0.16	21.06	54
180	1.8	43	0.18	23.69	58
200	2	46	0.2	26.3	64
220	2.2	51	0.22	28.9	70
240	2.4	55	0.24	31.6	75
260	2.6	58	0.26	34.2	80
280	2.8	63	0.28	36.8	86
300	3	68	0.3	39.4	93
320	3.2	72	0.32	42.1	100
340	3.4	76	0.34	44.7	107
360	3.6	82	0.36	47.4	112
380	3.8	86	0.38	50	119
400	4	90	0.4	52	124
420	4.2	95	0.42	55.1	130
440	4.4	100	0.44	57.6	138
460	4.6	104	0.46	60.4	142
480	4.8	109	0.48	63.0	150
500	5.0	112	0.50	65.8	155
550	5.5	124	0.55	72.4	170
600	6.0	135	0.60	79.0	185
700	7.0	160	0.70	92.1	220
800	8.0	172	0.80	105.2	249
900	9.0	195	0.90	117.8	280
1000	10.0	218	1	131.6	310

1) Milli Pascal second
2) Second
3) Pascal second

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