

# Operating Instructions **Memograph M, RSG45**

Advanced Data Manager

Additional Instructions for Energy Option

Mass and energy calculation in water and steam  
applications





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# 1 General description of the function

## NOTICE

**This manual contains an additional description for a special software option.**

This supplementary manual is not a substitute for the Operating Instructions pertaining to the device!

- Detailed information can be found in the Operating Instructions and the additional documentation.

Available for all device versions via:

- Internet: [www.endress.com/deviceviewer](http://www.endress.com/deviceviewer)
- Smartphone/tablet: Endress+Hauser Operations App

The energy package offers 4 options for calculating water and steam applications using the input variables flow, pressure, temperature (or temperature differential):

- Energy calculation
- Mass calculation
- Density calculation
- Enthalpy calculation

Furthermore, energy calculations are also possible using glycol-based refrigerant media. In addition, the density of the media saved in the device can be calculated under operating conditions.

Also, it is possible to calculate the mass by measuring the flow rate using the differential pressure method (DP Flow calculation) for water, steam, liquids and gases.

By balancing the results against one another or by linking the results to other input variables (e.g. gas flow, electrical energy), users can calculate overall balances, efficiency levels etc. These values are important indicators for the quality of the process and form the basis for process optimization, maintenance. etc.

The internationally recognized standard IAPWS-IF 97 is used to calculate the thermodynamic state variables of water and steam.

## 1.1 Firmware history

Overview of unit software history:

Unit software Version / date	Software changes	FDM analysis software version	Version of OPC server	Operating Instructions
V02.00.00 / 08.2015	Original software	V01.03.00.00 and higher	V5.00.03.00 and higher	BA01412R/09/EN /01.15
V2.04.06 / 10.2022	Bug fixes	V1.06.03	V5.00.07.00	BA01412R/09/EN /02.22-00

## 2 Description of the applications

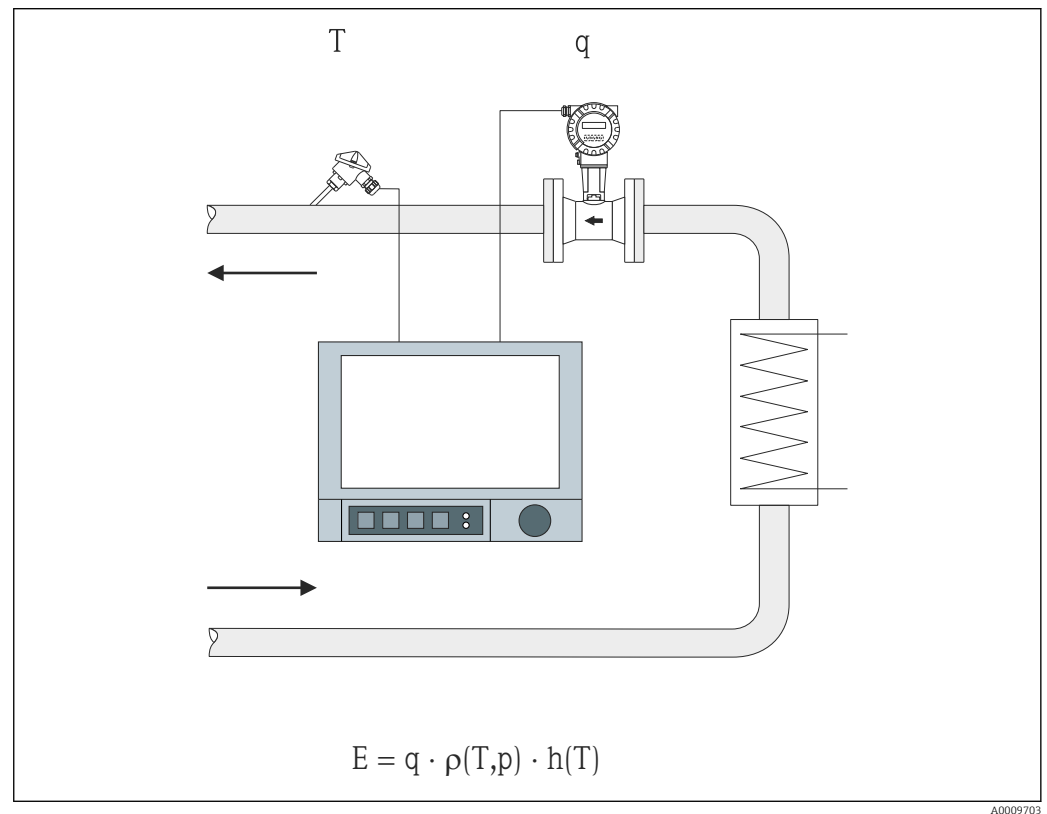
### 2.1 Water applications

#### 2.1.1 Water heat quantity

Calculation of the quantity of heat in a flow of water. Example: Determining the residual heat in the return line of a heat exchanger.

**Input variables:** operating volume and temperature

The average pressure is calculated automatically based on the temperature measured.



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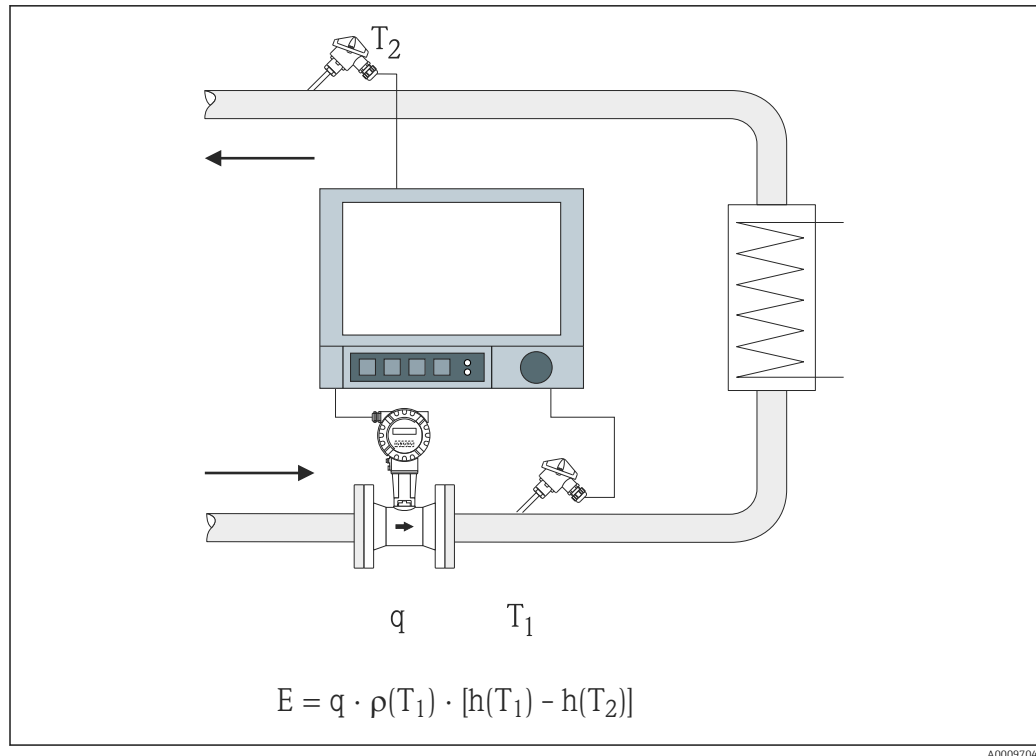
E	Quantity of heat
q	Operating volume
ρ	Density
T	Operating temperature
h	Specific enthalpy of water (in relation to 0 °C)

#### 2.1.2 Water heat difference

Calculation of the quantity of heat which is given off, or taken in, by a flow of water in a heat exchanger. Typical application for measuring energy in heating or cooling circuits.

**Input variables:** measurement of the operating volume and the temperature directly upstream and downstream from a heat exchanger (in the feed line or return line).

The flow sensor can be installed on the warm or cold side.



- E Quantity of heat
- q Operating volume
- $\rho$  Density
- $T_1$  T warm
- $T_2$  T cold
- $h(T_1)$  Specific enthalpy of water at temperature 1
- $h(T_2)$  Specific enthalpy of water at temperature 2

**i** For other heat carriers, such as thermal oil, the heat quantity is calculated using polynomials for density and thermal capacity. The formula editor of the mathematics channels is used to enter the polynomials. Polynomials for customer-specific liquids can be generated on request (subject to a fee).

## 2.2 Water/glycol applications

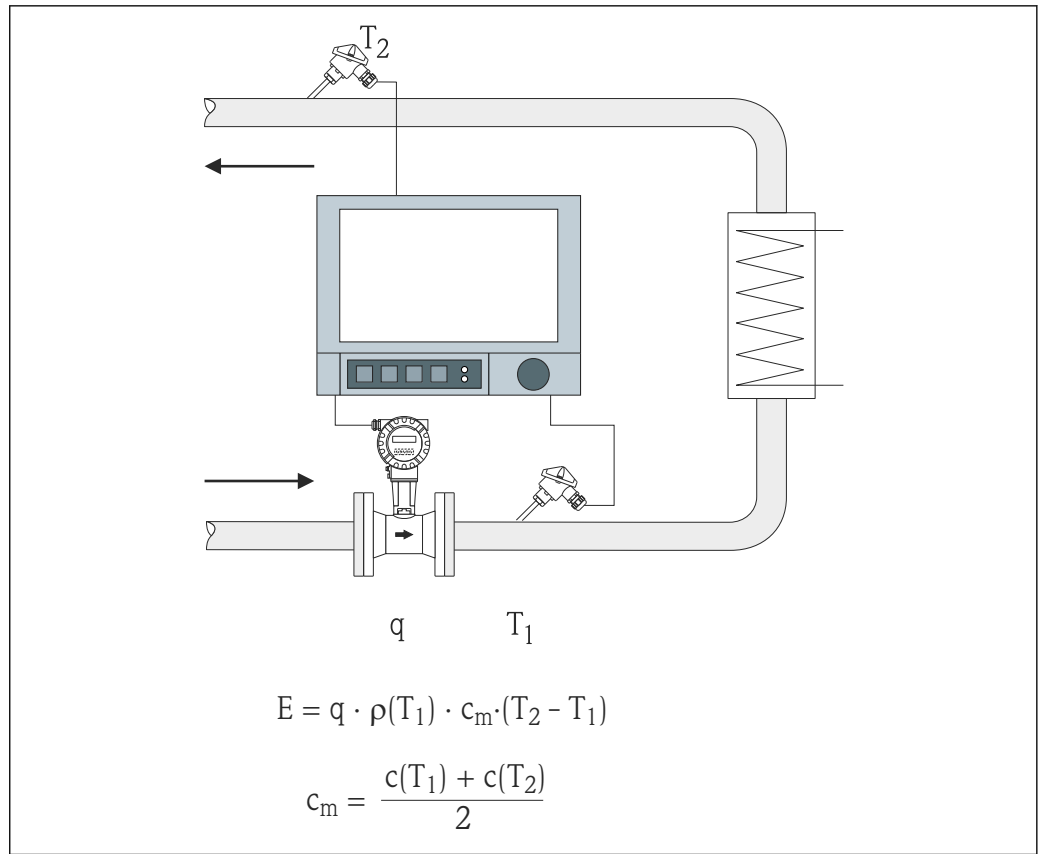
### 2.2.1 Water/glycol heat difference

Calculation of the quantity of heat which is given off, or taken in, by a refrigerant medium (water/glycol mixture) in a heat exchanger. Typical application for measuring energy in heating or cooling circuits.

**Input variables:** measurement of the operating volume and the temperature directly upstream and downstream from a heat exchanger (in the feed line or return line).

The density and thermal conductivity of the refrigerant medium are calculated based on the mixture ratio (concentration).

The flow sensor can be installed on the warm or cold side.



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E Quantity of heat

q Operating volume

$\rho$  Density

$T_1$  T warm

$T_2$  T cold

$c(T_1)$  Specific heat capacity at temperature 1

$c(T_2)$  Specific heat capacity at temperature 2

$c_m$  Average specific heat capacity



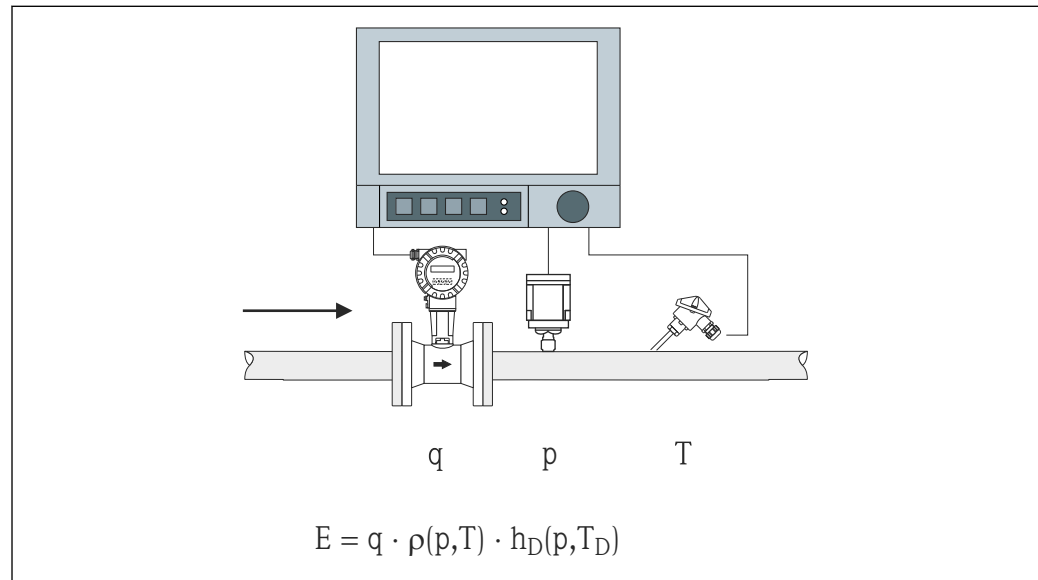
For other refrigerant media, specific polynomials for calculating the quantity of heat can be generated on request (subject to a fee).

## 2.3 Steam applications

### 2.3.1 Steam quantity of heat

Calculation of the mass flow and the quantity of heat it contains at the output of a steam generator or for individual consumers.

**Input variables:** operating volume flow, temperature and/or pressure



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E	Quantity of heat
q	Operating volume
ρ	Density
T <sub>D</sub>	Temperature of steam
p	Pressure (steam)
h <sub>D</sub>	Specific enthalpy of steam

For simplified measurement of saturated steam, you do not need to measure the pressure or temperature. The missing input variable is determined using the saturated steam curve stored in the system.

When measuring pressure and temperature, the steam state is determined exactly and monitored. A wet steam alarm is output when the saturated steam temperature = condensate temperature (see → 20)

### 2.3.2 Steam heat differential

Calculation of the quantity of heat given off when the steam condenses in a heat exchanger.

Alternatively, also calculation of the quantity of heat (energy) which is used to generate steam.

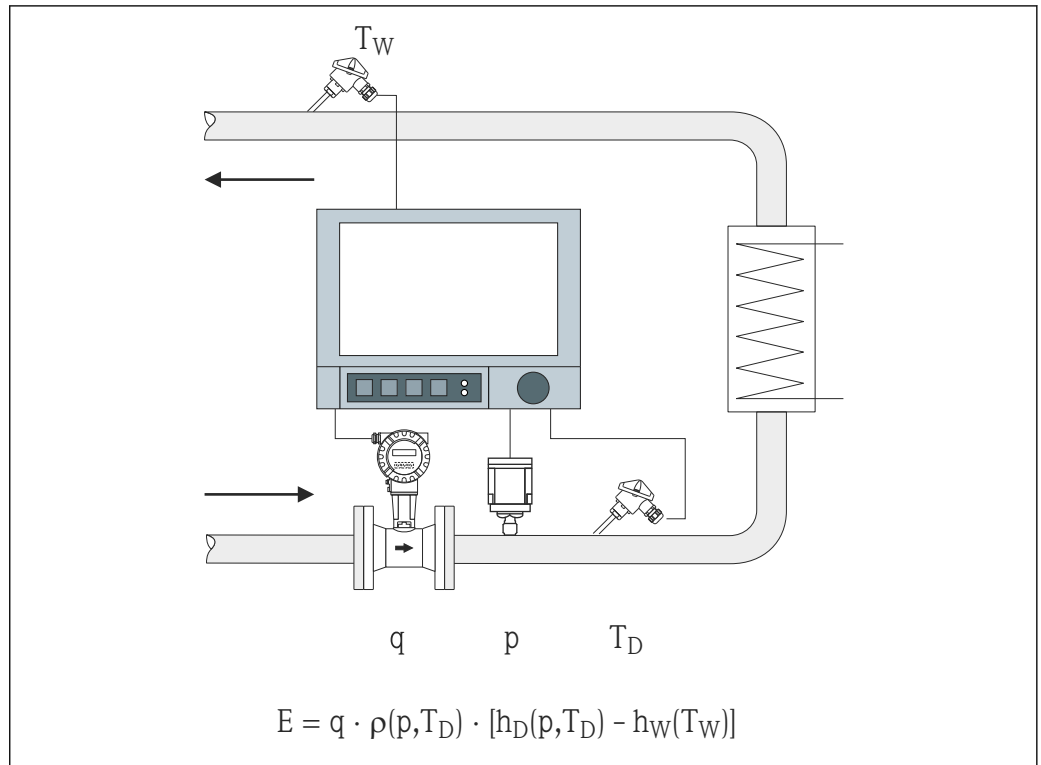
**Input variables:** measurement of the pressure and temperatures directly upstream and downstream from a heat exchanger (or steam generator).

The flow sensor can either be integrated in the steam pipe or the water pipe (condensate or feed water).

If flow measurement is required in both the steam pipe and the water pipe (e.g. due to steam consumption or loss), two applications need to be set up, namely steam heat



quantity and water heat quantity. The quantities of mass and energy can then be balanced in a mathematics channel using the formula editor (see → 18).





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E	Quantity of heat
q	Operating volume
ρ	Density
T <sub>D</sub>	Temperature of steam
T <sub>W</sub>	Temperature of water (condensate)
p	Pressure (steam)
h <sub>D</sub>	Specific enthalpy of steam
h <sub>W</sub>	Specific enthalpy of water

## 3 Application setup

### 3.1 General programming guidelines

#### Set the flow, pressure and temperature inputs.

The standard inputs are used for this purpose. Preferably, the units for scaling the measuring ranges should be taken from the table below (see →  10). Otherwise, conversion coefficients must be defined when defining the application (see →  10).

1. Open the mathematics channel.
2. Activate the function for calculating the energy or mass and select the application.
3. Assign inputs and define units.
4. Select units for the totalizers in the **Totalization** menu.
5. For steam applications, configure the fault mode in the event of a wet steam alarm, if applicable.
6. Configure the display, i.e. group the values for displaying and selecting the display mode.

### 3.2 Selecting the units

The units for the inputs and the application are selected within the context of configuring the application (in the mathematics channel). Please ensure that the units selected here are identical to the units that were used to scale the inputs.

If you prefer other units for configuring the inputs, a mathematics channel must be selected where the unit has to be converted to a unit indicated in the table. This mathematics channel is then used as a flow input in another mathematics channel to calculate the energy or mass.

Flow	m <sup>3</sup> /h	ft <sup>3</sup> /h	gal/h	ft <sup>3</sup> /min	GPM	l/h			
Pressure	bar(a)(g)	Psi(a)(g)	MPa(a)(g)	inH <sub>2</sub> O(a)(g)					
Density	kg/m <sup>3</sup>	lb/ft <sup>3</sup>							
Temperature	°C	K	°F						
Heat flow	kW	MW	kBTU/h	MBTU/h	ton	kBTU/ min	therm/ min	therm/h	GJ/h
Heat energy	kWh	MWh	MJ	MBTU	tonh	kBTU	therm	GJ	
Mass flow	kg/h	t/h	lbs/h	ton/h					
Mass sum	kg	t	lbs	ton					
Enthalpy	kJ/kg	Btu/lbs							

gal = gallons liquid: 1 ft<sup>3</sup> = 7.48051948 gal

ton (mass) = ton (short) US: 1 ton = 907.184 74 kg

ton (power) = ton refrigeration (TR): 1 ton = 3.516 852 84 kW

BTU = International [Steam] Table (IT): 1 Btu = 1055.056 kJ

therm = therm US (based on BTU59 °F): 1 therm = 105 480.4 kJ

GPM = gallons per minute

### 3.3 Examples for water and steam energy measurement

#### 3.3.1 Example of water heat difference

##### Setting the flow, pressure and temperature inputs

1. Select the signal.
2. Enter the name for the channel identifier.
3. Define the unit (see table → 10).
4. Set the measuring range.

/.../Universal inputs  
 Add input : No  
 Delete input : No  
 ▶ Flow (1) (active)  
 ▶ Temperature warm (2) (active)  
 ▶ Temperature cold (3) (active)  
 X Back

ESC Help

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/.../Temperature warm (2) (active) 220000-001  
 Signal : Current  
 Range : 4-20 mA  
 Channel ident. : Temperature warm  
 Plot type : Average  
 Engineering unit : °C  
 Decimal point : One (X.Y)  
 Range start : 0,0 °C  
 Meas. range end : 200,0 °C  
 Zoom start : 0,0 °C  
 Zoom end : 200,0 °C  
 Damping : 0,0 s  
 ▶ Totalization  
 ▶ Linearization  
 Copy settings : No  
 X Back

ESC Help

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##### Configuring energy calculation

1. Open the mathematics channel.
2. Select energy calculation.

3. Assign the sensors and units.
4. Specify the installation point of the flow sensor.
5. Set the zoom range.

/.../Maths 1		400005-000
Function	: Energy calculation	
Channel ident.	: Math 1	
Application	: Water heat difference	
Flow	: Flow	
Engineering unit	: m³/h	
Flow installation point	: cold	
Temperature warm	: Temperature warm	
Temperature cold	: Temperature cold	
Engineering unit	: °C	
Plot type	: Instantaneous value	
Engineering unit	: kW	
Decimal point	: One (X.Y)	
Zoom start	: 0 kW	
Zoom end	: 100 kW	
► Totalization (active)		

ESC Help

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### Selecting the unit for the totalizers

1. Activate totalization.
2. Select the unit and set the threshold value (low flow cutoff) if necessary (values that are smaller than the threshold value are not totalized).

/.../Totalization (active)		400053-000
Totalization	: Yes	
Total. eng. unit	: kWh	
Low flow cut off	: 0 kW	
Totalizer	: 0 kWh	
X Back		

ESC Help

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### Configuring the display

- Select the values and display format for the display.

././Group 1 (active)	
Identifier	: Group 1
Save cycle	: 1min
Alarm cycle	: 1s
Display blue	: Flow
Display	: Measured value/state
Display black	: Temperature warm
Display	: Measured value/state
Display red	: Temperature cold
Display	: Measured value/state
Display green	: Math 1
Display	: Measured value/state
Display violet	: Math 1
Display	: Totalizer
Display orange	: Switched off
Display cyan	: Switched off

ESC Help

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### 3.3.2 Example for steam quantity of heat / mass

#### Setting the flow, pressure and temperature inputs

1. Select the signal.
2. Enter the name for the channel identifier.
3. Define the unit (see table → 10).
4. Set the measuring range.

././Temperature cold (3)		220016-002
Signal	: Resistance therm., RTD	
Range	: Pt100 (IEC)	
Connection	: 4-wire	
Channel ident.	: Temperature	
Plot type	: Average	
Engineering unit	: °C	
Decimal point	: One (X.Y)	
Range start	: -200,0 °C	
Meas. range end	: 850,0 °C	
Zoom start	: -200,0 °C	
Zoom end	: 850,0 °C	
Damping	: 0,2 s	
► Totalization		
► Linearization		
Copy settings	: No	

ESC Help

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#### Configuring energy calculation

1. Open the mathematics channel.
2. Select energy or mass calculation.

3. Assign the sensors and units.
  - ↳ If you want to calculate and display the energy and mass, copy the settings to mathematics channel 2 and select "Mass calculation" there.

././Maths 1 (active)
400005-000


Function	: Energy calculation
Channel ident.	: Math 1
Application	: Steam heat quantity
Flow	: Flow
Engineering unit	: m <sup>3</sup> /h
Pressure	: Pressure
Engineering unit	: bar (a)
Temperature steam	: Temperature
Engineering unit	: °C
Plot type	: Average
Engineering unit	: MW
Decimal point	: One (X.Y)
Zoom start	: 0 MW
Zoom end	: 100 MW

▶ Totalization (active)
⬇

ESC

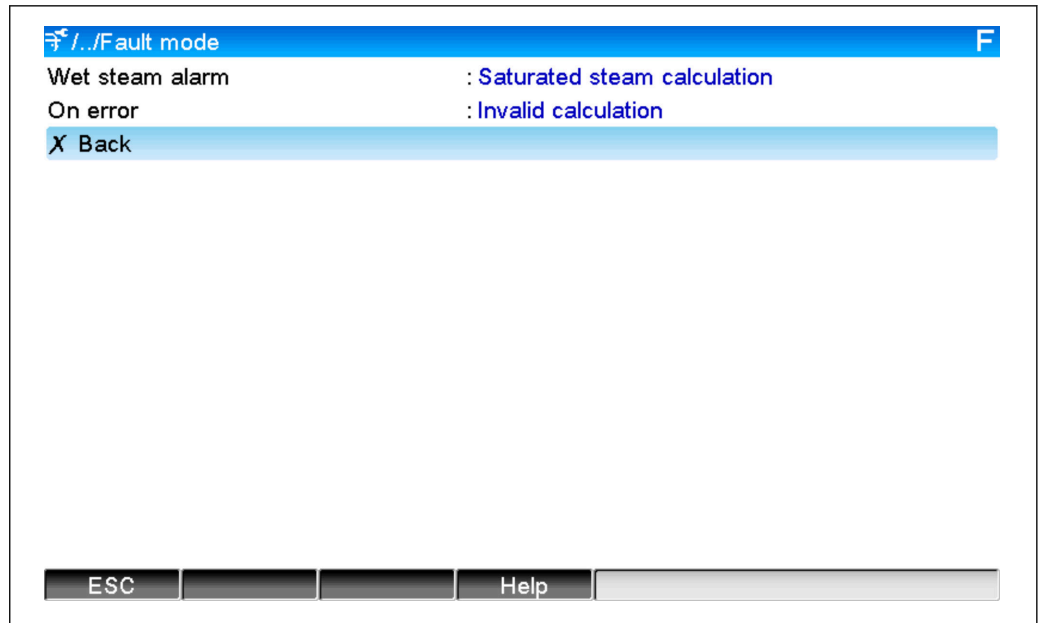
Help

### Selecting the unit for the totalizers

1. Activate totalization.
2. Select the unit and set the threshold value (low flow cutoff) where necessary (see example →  13, no. 2.2)

### Configuring the behavior in the event of a wet steam alarm (only possible if pressure and temperature inputs are used)

1. Activate Device setup/Expert.
2. Set the **Wet steam alarm** fault mode (counter stop in event of wet steam alarm or continue calculation with saturated steam conditions and continue totalization, i.e. counters continue to operate normally. Configure whether the wet steam alarm should be signaled via a relay).



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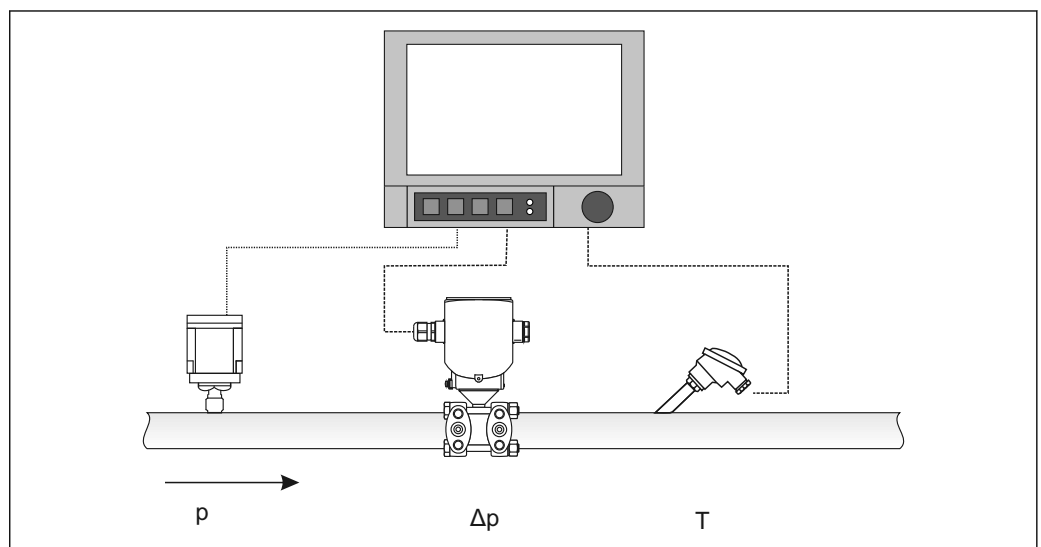
#### Configure the display.

- Select the values and display mode for the display (menu item: signal groups (see example → 13, no. 3))

### 3.3.3 DP flow calculation (flow measurement according to the differential pressure method)

#### General information

The device calculates the flow according to the differential pressure method as per the ISO5167 standard. Unlike conventional differential pressure measurement methods, which provide accurate results only under design conditions, the device calculates the coefficients of the flow equation (flow coefficient, velocity of approach factor, expansion number, density etc.) iteratively on a continuous basis. This ensures that the flow is always computed with the greatest of accuracy, even with fluctuating process conditions and completely independently of the design conditions (temperature and pressure in the sizing parameters).



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General ISO 5167 equation for orifice plates, nozzles and Venturi tube:

$$Qm = f \cdot c \cdot \frac{1}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot d^2 \frac{\pi}{4} \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$

Pitot tube:

$$Qm = k \cdot d^2 \frac{\pi}{4} \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$

Gilflo, V-cone (other DP flowmeters):

$$Qm = Qm(A) \cdot \sqrt{\frac{\rho_B}{\rho_A}}$$

Qm	Mass flow (compensated)
k	Blockage factor
ρ	Density under operating conditions
Δp	Differential pressure
QM(A)	Mass flow under design conditions
ρA	Density under design conditions
ρB	Density under operating conditions

Parameter configuration for differential pressure measurement

Configuration of a universal input for the differential pressure transmitter:

1.

Select the signal (4-20mA).
2.

Enter the channel identifier.
3.

Enter the unit (mbar).
4.

Enter the measuring range of the differential pressure transmitter.

↗

Universal input 4

F

Signal

: Current

Range

: 4-20 mA

Channel ident.

: Diff pressure

Plot type

: Average

Engineering unit

: mbar

Decimal point

: One (X.Y)

Range start

: 0,0 mbar

Meas. range end

: 100,0 mbar

Zoom start

: 0,0 mbar

Zoom end

: 100,0 mbar

Damping

: 0,0 s

▶ Totalization

▶ Linearization

Copy settings

: No

X Back

ESC

Help

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The remaining settings are configured in the mathematics channel and in the DP-Flow submenu:

1.

Select the application (water, steam, liquids, gas).



2. Select the design and material of the differential pressure transmitter, e.g. orifice plate, nozzle.
3. Enter the internal diameter "D" of the pipe at 20 °C (68 °F).
4. Enter the diameter "d" of the differential pressure transmitter (or k-factor for Pitot tubes) at 20 °C (68 °F).

**Maths 1 (active)** F

Function	: Mass calculation DP flow
Channel ident.	: Math 1
Application	: Water DP flow
Device type	: Orifice (Corner)
Temp.	: Temperature
Engineering unit	: °C
Plot type	: Average
Engineering unit	: kg/h
Decimal point	: One (X.Y)
Zoom start	: 0 kg/h
Zoom end	: 100 kg/h
▶ DP flow	
▶ Totalization (active)	
Copy settings	: No
X Back	

ESC Help

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**DP flow** F

Differential pressure	: Diff pressure
DP unit	: mbar
Diameter unit	: mm
D at 20°C	: 100 mm
d at 20°C	: 70 mm
Pipe material	: C-steel
Device material	: C-steel
X Back	

ESC Help

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Density under operating conditions: The density must be determined under operating conditions for liquids other than water and glycol and for gases. The density can either be calculated in a mathematics channel or determined externally and transmitted to the device. The general formula for determining the density of gases is:

$$\rho(b) = \rho(b) \cdot \frac{p}{pn} \cdot \frac{Tn}{T}$$

$\rho(b)$	Density under operating conditions
$\rho(n)$	Density under normal conditions
$p$	Operating pressure in bar
$p(n)$	Pressure under normal conditions in bar (e.g. 1.013 bar)
$T(n)$	Temperature in Kelvin under normal conditions (e.g. 273 Kelvin)
$T$	Operating temperature in Kelvin (i.e. temperature in °C +273.15)

For liquids, the density data can be entered in tabular form under "Expert/Application/Mathematics/Math x/Linearization". The mathematics channel is then assigned in the "Density" field.

## 3.4 Balancing (linking of applications)

### 3.4.1 General

To balance mass or energy amounts against one another or to calculate characteristic values, any mathematics channel can be used.

**Example:** Balancing of a steam plant

- The heat quantity of the generated steam is calculated in mathematics channel 1.
- Mathematics channel 2 is used to calculate the residual energy in the flow of condensate (water heat quantity)

**Looking for:**

Energy that was given off between the steam feed line and the condensate return line.

**Solution:**

1. Open mathematics channel 3.
  2. Select the formula editor.
  3. Subtract the energy flows (current values) from one another and totalize (integration).
    - ↳ Alternatively, the counters can also be subtracted directly.
- Formula:**  $MI(3;1) - MI(3;2)$

### 3.4.2 Monitoring steam boilers

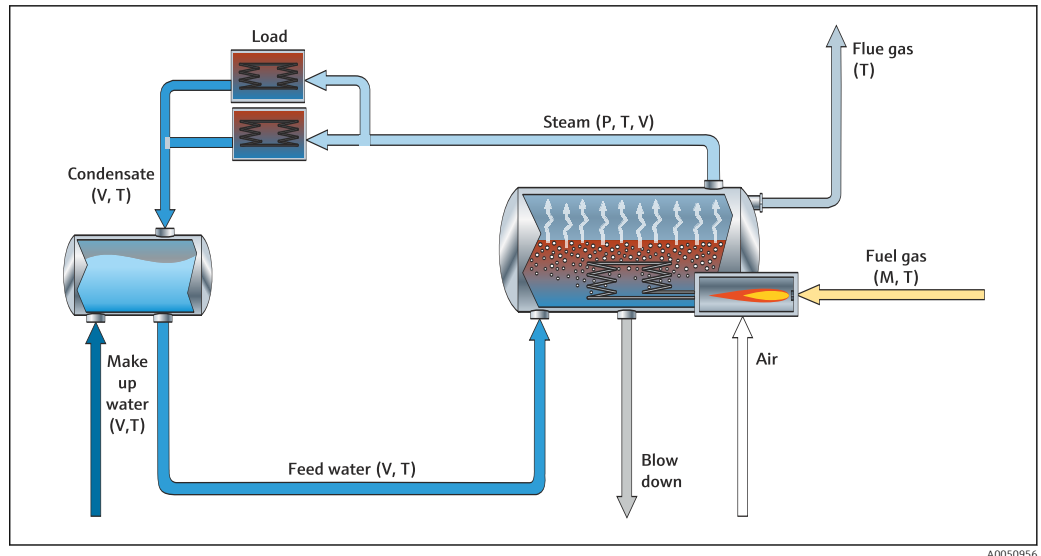
A steam boiler is monitored to ensure plant safety and to optimize processes and thus save costs.

Measured variables for monitoring plant safety:

- Level
- Boiler pressure
- Boiler temperature

Measured variables and characteristic values for process optimization:

- Energy of steam flow
- Energy of condensate flow
- Energy of feed water or fresh water
- Energy of boiler blow down
- Energy of fuel (e.g. natural gas, heating oil)
- Energy, oxygen content and temperature of the flow of flue gas
- Mass flow of combustion air (incl. O<sub>2</sub> content and temperature)
- Chemical analysis: pH, dissolved oxygen, conductivity



### Example: Calculation of boiler efficiency

- Mathematics channel 1 (M1) : steam heat quantity (totalization: counter)
- Mathematics channel 2 (M2) : fuel heat quantity (totalization: counter)
- Mathematics channel 3 (M3) : efficiency of fuel to steam (as %)
- Mathematics channel 4 (M4) : ratio of fuel to steam

Configuration of mathematics channel 3:

/.../Effizienz (3) (active)		400002-002
Function	: Formula editor	
Channel ident.	: Efficiency	
Formula	: $MI(3;1)/MI(3;2)*100$	
The result is	: Efficiency	
Engineering unit	: %	
Decimal point	: One (X.Y)	
Copy settings	: No	
X Back		

ESC
Help

**i** The counter values of mathematics channel 1 and 2 must be used to calculate the efficiency. "Efficiency" must be selected for the "The result is" parameter. With this setting, the counter values of the signal analysis are automatically used for efficiency calculation and you receive 4 efficiency values (e.g. 15 min, day, month, year) to display and save.

**Devices pre-set to customer requirements can be ordered for the following steam applications:**

- Standard steam boiler efficiency (direct efficiency calculation)
- Steam boiler efficiency including evaluation of individual losses (stack loss, blow down, radiated emissions)
- Balancing of steam distribution including leak measurement
- Measurement of the steam consumption including determination of the specific steam requirement per production unit.

### 3.4.3 Additional solution packages for customer-specific applications

In addition to the solution packages for steam, pre-set devices can be ordered for additional customer-specific applications:

**Cooling system:**

- Calculation of the COP for the system, plant and cooling unit
- Balancing of cooling system distribution
- Calculation of specific cooling system usage (per production unit)

**Compressed air system:**

- Measurement of specific compressor performance (kWh/Nm<sup>3</sup>)
- Leak measurement
- Filter monitoring
- Calculation of specific compressed air consumption

**Heating system:**

- Efficiency of hot water boiler
- Balancing of heat distribution
- Calculation of specific heat consumption (per production unit)

**Wastewater:**

- Specific energy consumption based on wastewater load
- Specific aerator performance
- Specific pump performance
- Specific digester gas generation

## 3.5 Fault mode

The fault mode can only be configured in the Expert mode.

The settings for the fault mode of the inputs are described in Section 6.4 of the Operating Instructions for the Advanced Data Manager.

In the event of an error, calculation of the energy and mass is continued using a replacement value, or the calculation is invalid.

For steam applications, once the condensate temperature (wet steam alarm) is reached, the saturated steam condition is calculated based on T, and the heat flow (performance) is calculated. The behavior of the counters can be defined in the menu item Fault mode/Wet steam alarm:

- Totalization stop (counter stop)
- Continue totalization, i.e. the counters continue to run (saturated steam calculation)

## 4 Technical data

	Water	Water/glycol	Steam
Measuring range	0 to 350 °C (32 to 662 °F)	-40 to 350 °C (-40 to 662 °F)	
Measuring range for superheated steam			0 to 1 000 bar (0 to 14 503.7 psi) 0 to 800 °C (32 to 1 472 °F)
Measuring range for saturated steam			0 to 165 bar (0 to 2 393 psi) 0 to 373 °C (32 to 703 °F)
Min. temperature differential	0 °C (0 °F)		
Concentration		0 to 60 Vol %	
Error limits (universal inputs)	3 to 20 °C (37.4 to 68 °F) < 1.0 % of measuring range 20 to 250 °C (68 to 482 °F) < 0.3 % of measuring range		
Scan rate	500 ms		
Calculation standard	IAPWS-IF 97 EN1434	Polynomial functions (inaccuracy: max. 0.6 %)	IAPWS-IF 97







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