BA01644O/09/en/01.16
71342005

Firmware version
ENU000A, V02.01.xx

Additional instructions
Advanced Data Manager ORSG45

Energy option
Mass and energy calculation in water and steam applica-tions

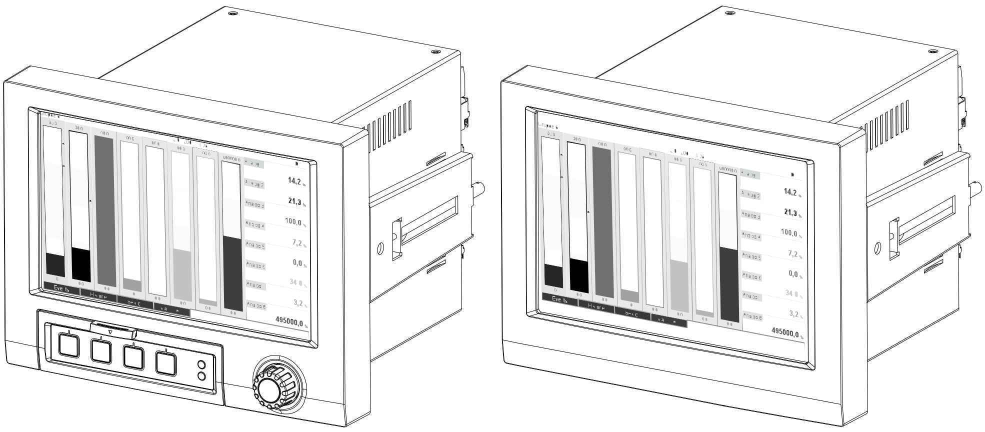


Table of contents

1 General information

1.1 Symbols

NOTICE

Note
Failure to observe this sign can result in a device (adapter) defect or a malfunction!

1.2 Firmware history

Overview of unit software history:

Unit software version / date	(Software) modification	Operating instructions of the Energy option
V2.01.04 / 06.2016	Update DP flow calculation; Bug fixes	BA01644O/09/en/01.16

1.3 General description of the function

NOTICE

This manual provides an additional description of a specific software option.

This additional manual does **not** replacer the relevant Operating Instructions!
Detailed information can be found in the Operating Instructions and the additional documentation.

The energy package offers 4 calculation options for 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 saved media can be calculated under the respective operating conditions.
In addition, it is possible to calculate 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 perform overall balances, calculate efficiency levels etc. These values are important indicators for the quality of the process and form the basis for process optimization efforts, maintenance, etc.

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

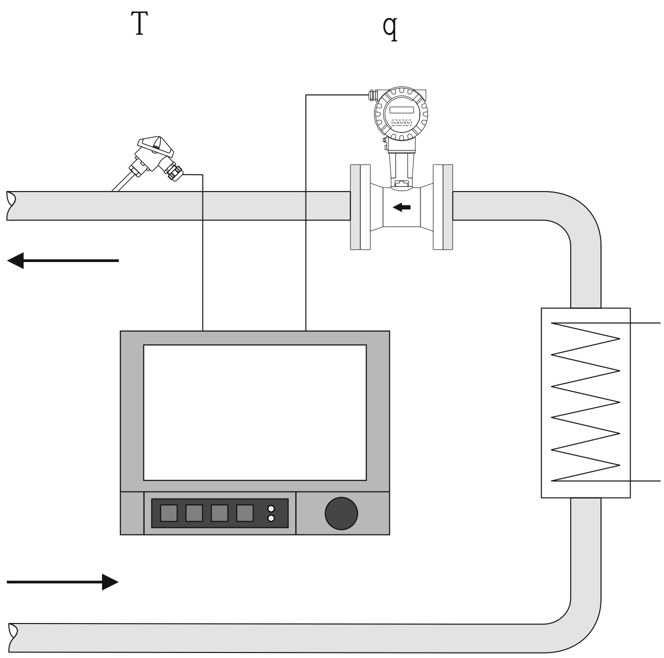
2 Description of the applications

2.1 Water applications

2.1.1 Water heat quantity

Calculating 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.



$$E = q \cdot \rho(T,p) \cdot h(T)$$

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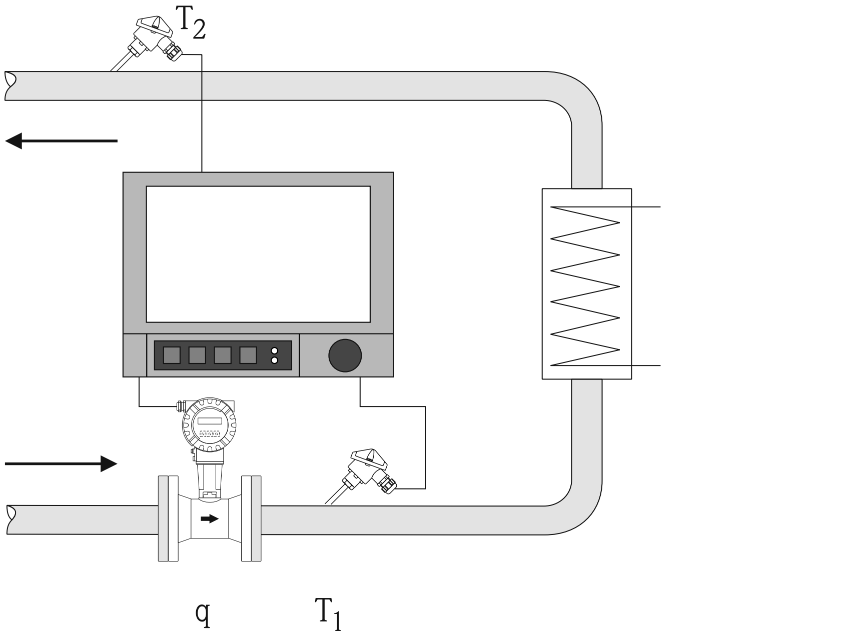
E:	Quantity of heat
q:	Operating volume
ρ:	Density
T:	Operating temperature
h:	Specific enthalpy of water (in relation to 0 °C)

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 and cooling circuits.
Input variables: Measurement of operating volume and 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.



$$E = q \cdot \rho(T_1) \cdot [h(T_1) - h(T_2)]$$

E:	Quantity of heat
q:	Operating volume
ρ:	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

NOTICE

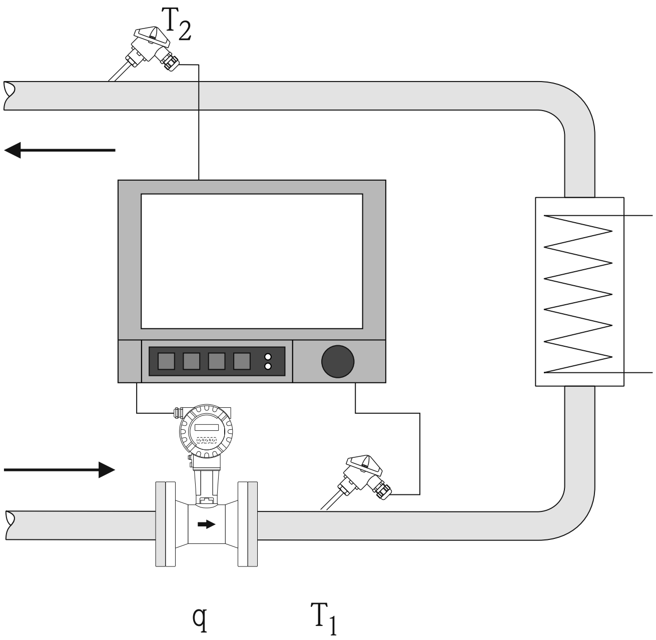
For other heat carriers, e.g. thermal oil, the quantity of heat is calculated using polynomials for density and heat capacity. To enter the polynomials, the formula editor for the mathematics channels is used. Polynomials for customer-specific liquids can be generated on request (subject to a fee).

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

The density and heat 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.



$$E = q \cdot \rho(T_1) \cdot c_m \cdot (T_2 - T_1)$$

$$c_m = \frac{c(T_1) + c(T_2)}{2}$$

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E:	Quantity of heat
q:	Operating volume
ρ:	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
cm	Average specific heat capacity

NOTICE

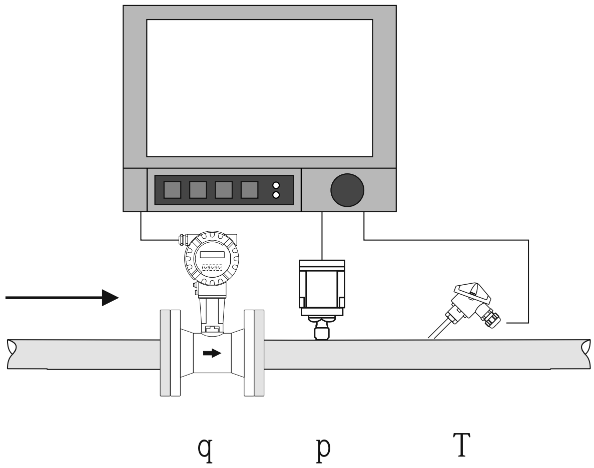
For other refrigerant media, specific polynomials for calculating the quantity of heat can be generated on request (subject to a fee).

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



$$E = q \cdot \rho(p,T) \cdot h_D(p,T_D)$$

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E:	Quantity of heat
q:	Operating volume
ρ:	Density
T_D:	Temperature of steam
p:	Pressure (steam)
h_D	Specific enthalpy of steam

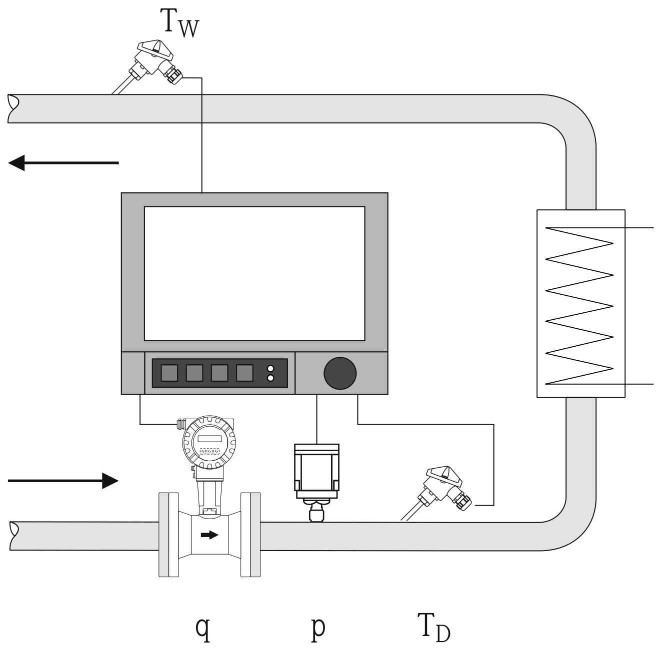
For simplified measurement of saturated steam, you can refrain from measuring the pressure or temperature. The missing input variable is determined using the saturated steam curve stored in the system.
When measuring pressure and temperature, the steam state is determined exactly and monitored. A wet steam alarm is output when the saturated steam temperature = condensate temperature. (See Fault mode 3.5)

2.3.2 Steam heat difference

Calculating the quantity of heat given off when the steam condenses in a heat exchanger. Alternatively, calculating the quantity of heat (energy) 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 losses), two applications must 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 with the aid of the formula editor (see 3.4.1).



$$E = q \cdot \rho(p,T_D) \cdot [h_D(p,T_D) - h_W(T_W)]$$

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E:	Quantity of heat
q:	Operating volume
ρ:	Density
T_D:	Temperature of steam
T_W:	Temperature of water (condensate)
p:	Pressure (steam)
h_D:	Specific enthalpy of steam
h_W:	Specific enthalpy of water

3 Application setup

3.1 General guidelines on programming

1. Set the flow, pressure and temperature inputs
   The standard inputs are used here. Preferably, the units for scaling the measuring ranges should be taken from the table below (see 3.2).
   Otherwise, conversion coefficients must be defined when defining the application (see 3.2).
2. Open the mathematics channel. Activate the function for calculating the energy or mass and select the application. Assign inputs and define units. Select units for the totalizers in the Totalization menu.
   For steam applications, configure the fault mode in the event of a wet steam alarm, if applicable.
3. 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 energy or mass.

Units in the energy package

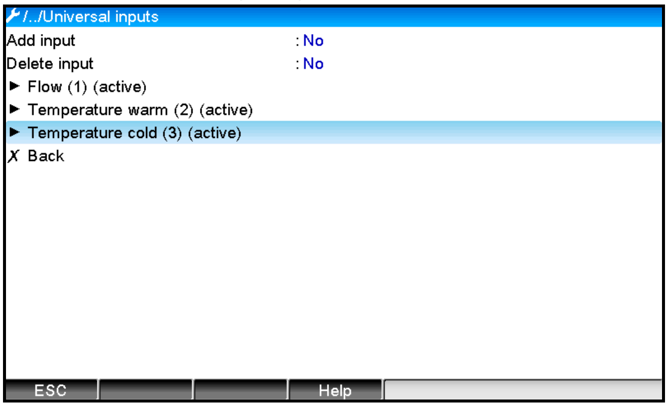
Flow	m^3/h	ft^3/h	gal/h	ft^3/min	GPM	l/h			
Pressure	bar(a)(g)	Psi(a)(g)	MPa(a)(g)	inH2O(a)(g)					
Density	kg/m^3	lb/ft^3							
Temperature	°C	K	°F						
Heat flow	kW	MW	kBTU/h	MBTU/h	ton	kBTU/ min	therm/ min	therm/h	GJ/h
Heat energy	kWh	MWh	MJ	MBTU	tonh	kBTU	therm	GJ	
Mass flow	kg/h	t/h	lbs/h	ton/h					
Mass sum	kg	t	lbs	ton					
Enthalpy	kJ/kg	Btu/lbs							

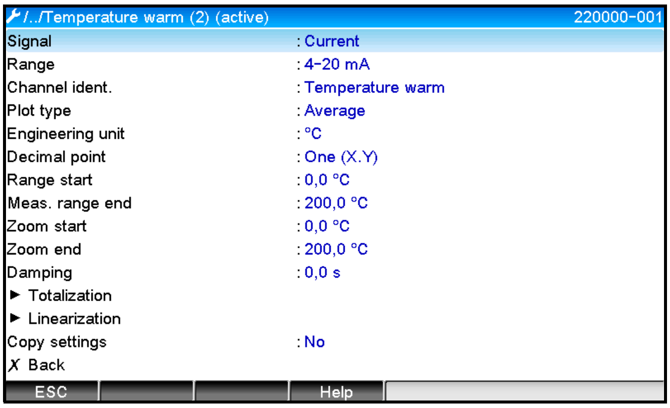
gal = gallons liquid: 1 ft^3 = 7.48051948 gal
ton (mass) = ton (short) US: 1 ton = 907.18474 kg
ton (power) = refrigeration ton (RT): 1 ton = 3.51685284 kW
BTU = International [Steam] Table (IT): 1 Btu = 1055.056 kJ
therm = therm US (based on BTU59 °F): 1 therm = 105 480.4 kJ
GPM = Gallons per Minute

3.3 Examples for water and steam energy measurement

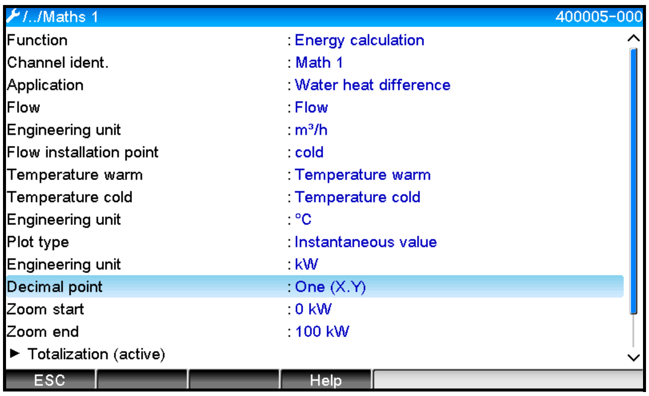
3.3.1 Example of water heat difference

1. Set the flow, pressure and temperature inputs.
   Select the signal, enter a name for channel identification, define the unit (see Table 3.2) and set the measuring range.

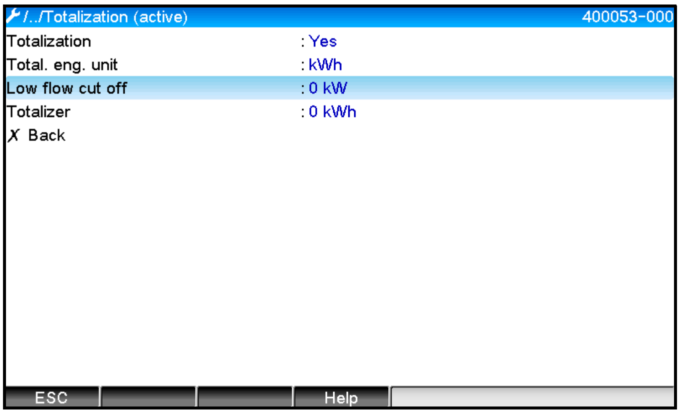




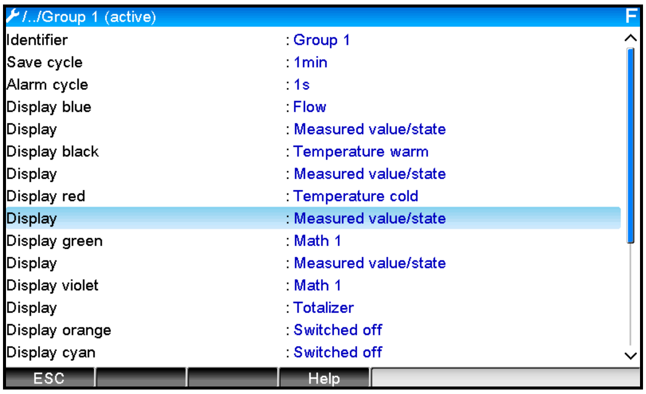
2. Configure energy calculation.
   2.1 Open the math channel, select energy calculation, assign sensors and units, specify the installation point of the flow sensor and set the zoom range.



2.2 Select the unit for the counters.
Activate totalization, select the unit and set the threshold value (low flow cutoff) if necessary (values less than the threshold value are not totalized).

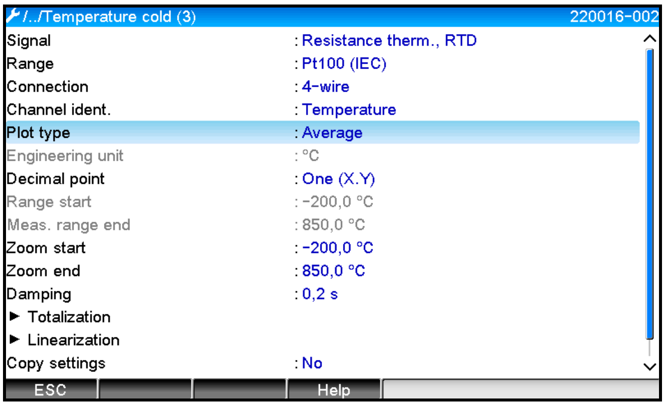


3. Configure the display.
Select the values and display mode for the display.

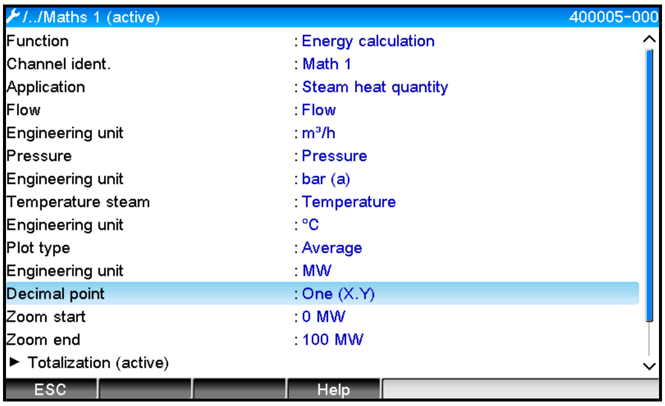


3.3.2 Example for steam heat quantity / mass

1. Set the flow, pressure and temperature inputs.
   Select the signal, enter a name for channel identification, define the unit (see Table 3.2) and set the measuring range.

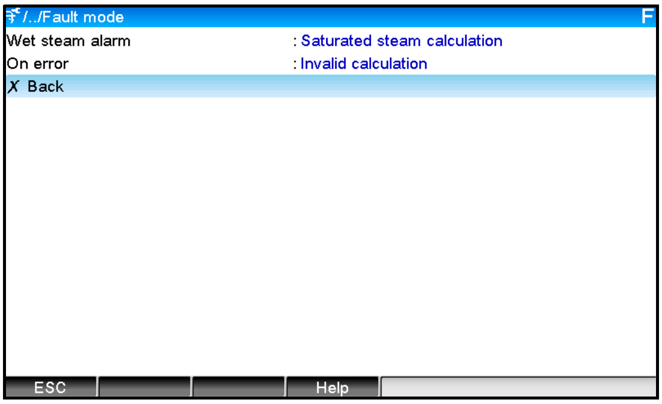


2. Configure energy calculation.
   2.1 Open the math channel, select energy or mass calculation, assign sensors and units.
   If you wish to calculate and display energy and mass, copy the settings to math channel 2 and select "Mass calculation" there.



   2.2 Select the unit for the counters.
   Activate totalization, select the unit and set the threshold value (low flow cutoff) if necessary (see example 3.2.2, no. 2.2)

2.3 Configure behavior for wet steam alarm.
(Only possible if pressure and temperature inputs are used.)
Open Expert menu, configure the wet steam alarm fault mode (counter stop in the event of wet steam alarm or continue calculation with saturated steam condition and continue totalization, i.e. counters continue to operate as normal. Configure whether the wet steam alarm should be signaled via a relay).

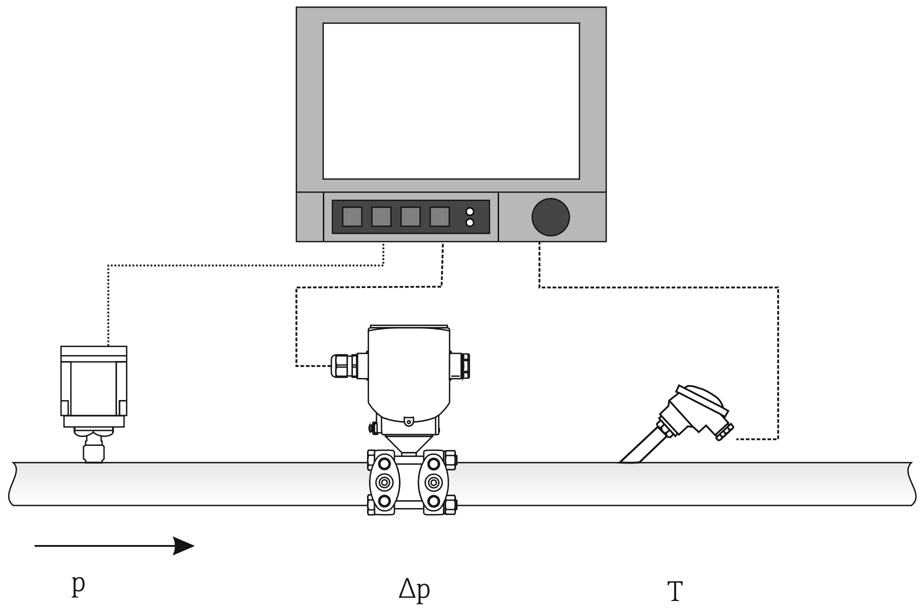


3. Configure the display.
Select the values and display mode for the display (menu: signal groups (see example 3.2.2, no. 3)

3.3.3 DP flow calculation (flow measurement based on the differential pressure method)

General notes

The device calculates the flow rate using the differential pressure method as per the ISO5167 standard. Unlike the conventional method of differential pressure measurement, which provides accurate results only under design conditions, the device calculates the coefficients of the flow equation (flow coefficient, velocity of approach factor, expansion factor, density etc.) iteratively on a continuous basis. This ensures that the flow rate is calculated accurately even under fluctuating process conditions and fully independently of the design conditions (temperature and pressure under design conditions).



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:

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

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Gilflo, V-cone (other DP flowmeters):

$$Qm = Qm(A) \cdot \sqrt{\frac{\rho B}{\rho A}}$$

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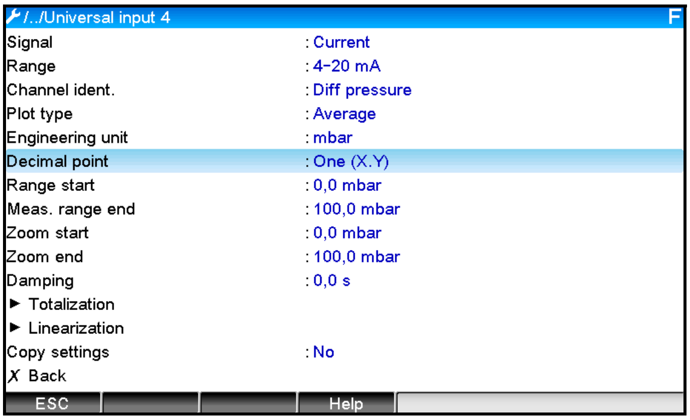
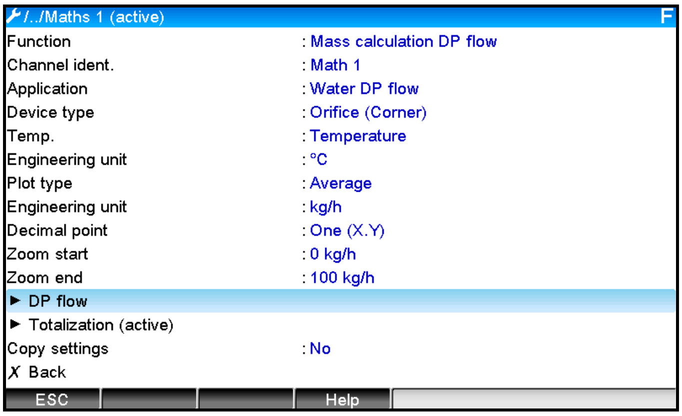
Qm	Mass flow (compensated)
k	Blockage factor
ρ	Density under operating conditions
$\Delta\rho$	Differential pressure
QM(A)	Mass flow under design conditions
ρ_A	Density in design conditions
ρ_B	Density under operating conditions

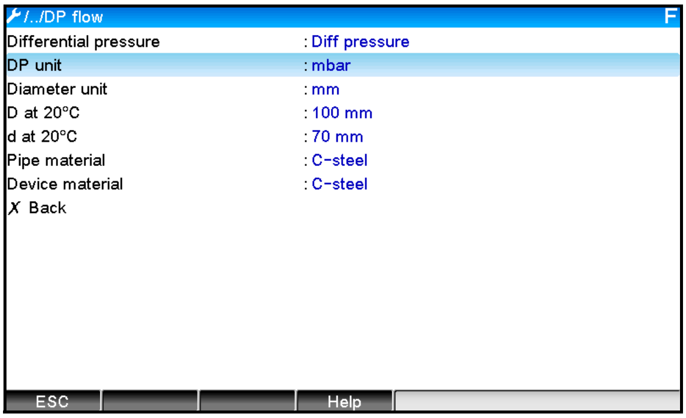
Configuration of differential pressure measurement

1. Set a universal input for the differential pressure transducer:
   – Select signal (4-20mA)
   – Channel description
   – Unit (mbar)
   – Measuring range of differential pressure transducer



2. Additional settings are made in the math channel and in the DP flow submenu:
   – Application (water, steam, liquids, gas)
   – Design and material of differential pressure transducer, e.g. orifice place, nozzle
   – Internal diameter "D" of pipe at 20 °C (68 °F)
   – Diameter "d" of differential pressure transducer (or k factor for pitot tubes) at 20 °C (68 °F)





Density under operating conditions: For other liquids besides water and glycol as well for gases, the density must be determined under operating conditions. The density can be calculated either in a mathematics channel or determined externally and transmitted to the device. The general formula for calculating 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 standard conditions
p	Operating pressure in bar
$p(n)$	Pressure under standard conditions in bar (e.g. 1.013 bar)
$T(n)$	Temperature in Kelvin under standard 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/ Maths/Maths x/Linearization". The relevant math channel is then assigned in the "Density" field.

3.4 Balancing (linking applications)

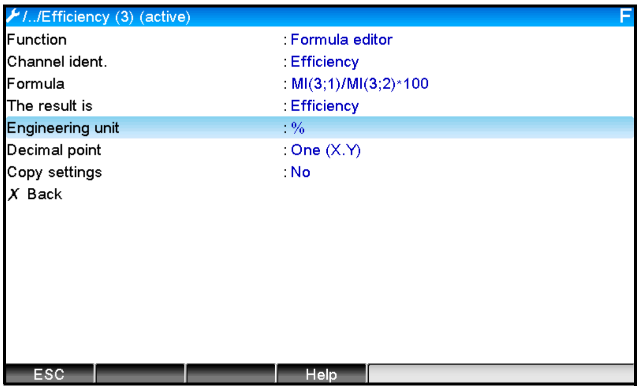
3.4.1 General

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

Example: Balancing a steam system

- In math channel 1, the heat quantity of the generated steam is calculated.
- Math channel 2 is used to calculate the residual energy in the flow of condensate (water heat quantity).

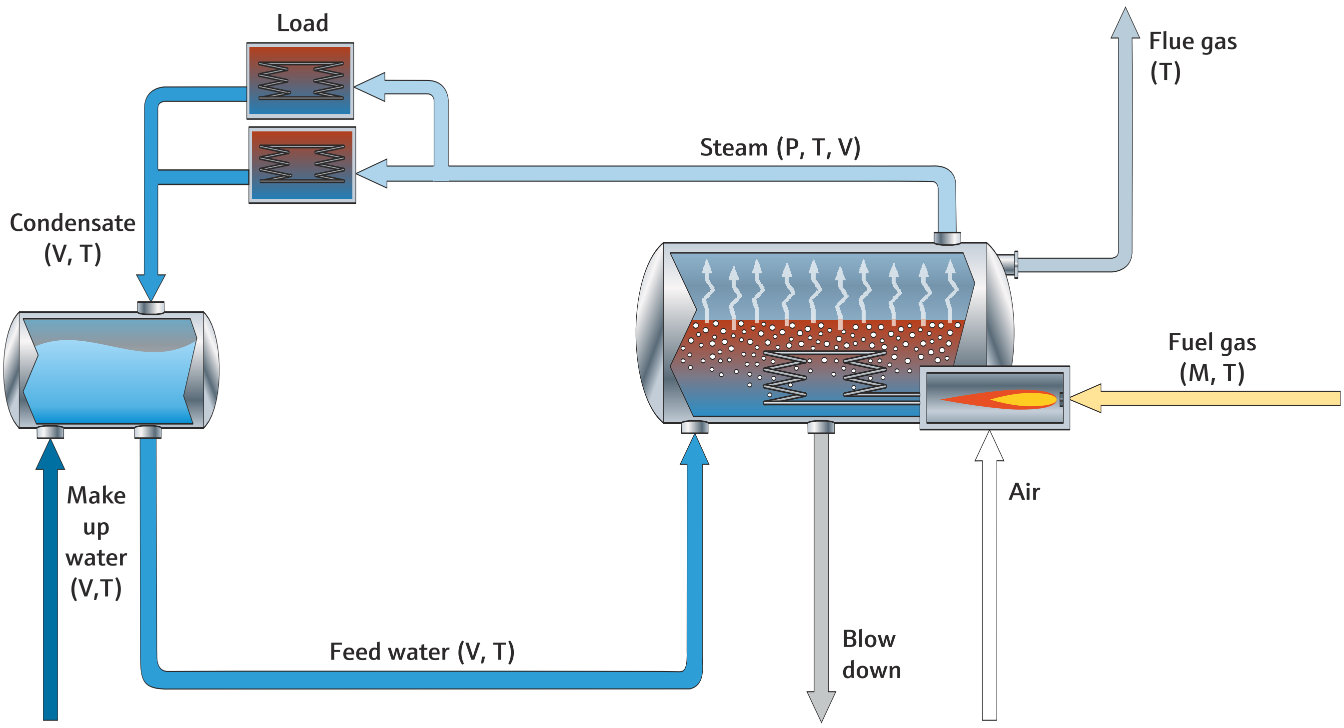
Looking for:
Energy that was given off between the steam feed line and the condensate return line.
Solution:
Open math channel 3, select the formula editor and use it to subtract the energy flows (current values) from one another and totalize (integration). Alternatively, the counters may also be subtracted directly.



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

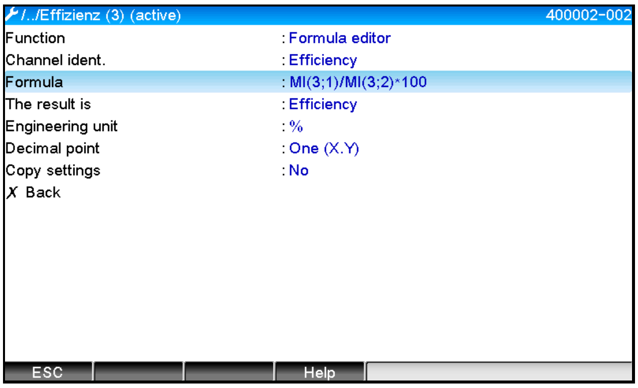
Measured variables and characteristic values for process optimization:
- Energy of steam flow
- Energy of condensate flow
- Energy of feed water or fresh water
- Energy of boiler blowdown
- Energy of fuel (e.g. natural gas, heating oil)
- Energy, oxygen content and temperature of the flow of flue gas
- Mass flow of combustion air (incl. O_2 content and temperature)
- Chemical analysis: pH, dissolved oxygen, conductivity



Example: Calculation of boiler efficiency

- Math channel 1 (M1) : Steam heat quantity (totalization: counter)
- Math channel 2 (M2) : Fuel heat quantity (totalization: counter)
- Math channel 3 (M3) : Efficiency of fuel to steam (as %)
- Math channel 4 (M4) : Ratio of fuel to steam

Configuration of math channel 3:



NOTICE

To calculate efficiency, the counter values from math channel 1 and 2 must be used. "Efficiency" must be selected in the "The result is" parameter. This ensures that the counter values from the signal evaluation are used automatically 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:

- Steam boiler efficiency standard (direct efficiency calculation)
- Steam boiler efficiency including evaluation of individual losses (stack loss, blowdown, radiation)
- Balancing of steam distribution including leak measurement
- Measurement of steam consumption including calculation of 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 COP for system, plant and cooling machine
- Balancing of a cooling system distribution
- Calculation of specific cooling system usage (per production unit)

Compressed air system:
- Measurement of specific compressor performance (kWh/Nm³)
- 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 biogas generation

3.5 Fault mode

The fault mode can be configured only in 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 1000 bar (0 to 14503.7 psi) 0 to 800 °C (32 to 1472 °F)
Measuring range for saturated steam			0 to 165 bar (0 to 2393 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