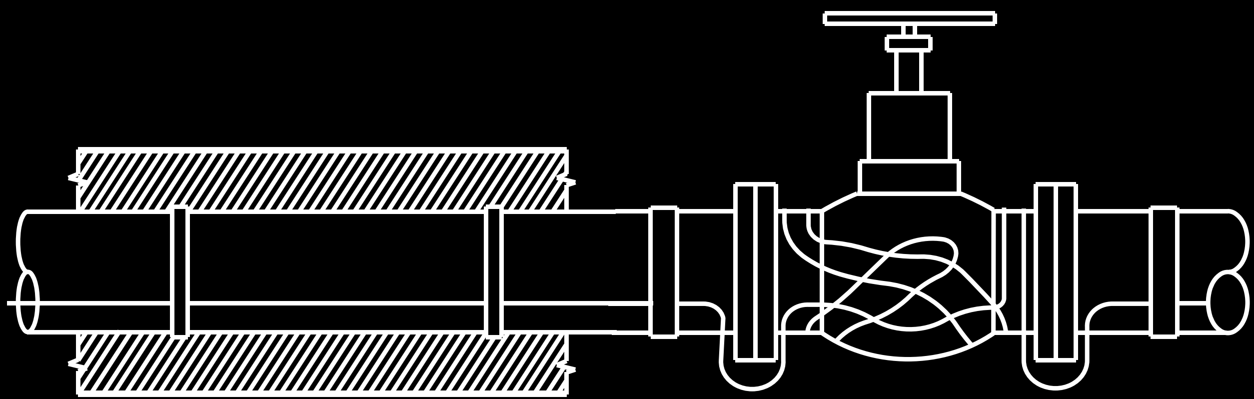
Engineering Manual



Heat Tracing Systems
Electrical Surface Heating

HTS Global AG
Gubelstrasse 12 • CH-6300 Zug • Switzerland • Phone: (+41) 43 210 7504
Fax: (+41) 43 210 7505 • Mail: info@hts-global.com

www.hts-global.com

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Heating Fundamentals
This section deals with the basic fundamentals of heat transfer and heat losses. The heat transfer process may be broken down into three basic modes.

Convection
Conduction
Radiation

Convection. Heat is absorbed and/or transfered by circulating particles that come into contact with other heated particles or substances, such as liquids and gases, for example hot air circulation.

Conduction. Heat is transfered within a medium from molecule to molecule without changing the form of the medium, for example water or oil. The rate of heat transfer is dependent upon the amount of resistance between materials of different temperatures.

Radiation. The heat is tranfered through electromagnetic waves that a warmer substance sends and a colder substance absorbs, such as electrical trace heating on a pipeline.

Thermodynamic properties
The physical changes and weights of materials are influenced through it's thermodymaic properties. This is mainly through the temperature characterized, which changes the material's pressure and volume characteristic. For this reason temperature, pressure and volume belong to the basic values of themodynamic material properties.

All materials have individual thermodynamic properties and physical characteristics. These constants and characteristics are used in heat energy calculations. These are:

Specific heat (C_p)
Density (ρ)
Volume (m^3 , dm^3 , l, cm^3)
Thermal resistance (λ)

Specific heat. Materials contain or absorb different amounts of energy. The amount that the material contains or absorbs is called it's specific heat. The specific heat is based upon the amount of energy required to raise the temperature of one kilogramm material by one degree Celcius.

Density. The density is the weight of a material for each volume measurement.

Volume. The most common measurements of materials in a certain space are cubic meter (m^3), cubic decimeter (dm^3) or liter (l), and cubic centimeter (cm^3).

Thermal conductivity. This is the amount of energy that transfers from one side of a cube, with 1m side length, to the other side of the cube within one hour and a temperature difference from these side of 1 Kelvin (K). The thermal resistance value (λ) is the expansion value and the specific thermal resistance that is dependent on temperature change and material.

Electrical Surface Heating
The main objective of any heating application is to raise or maintain the temperature of a material, gas, process, or to compensate for heat losses that are not adequately prevented by the usage of insulation.

Some of the most common electrical surface heating applications are:

frost protection of piplines
process heating
temperature maintenance of pipelines
anti-condensation heating
heating of transport containers
de-icing and ice prevention
vulcanization and curing processes
temperature maintenance of vacuum processes
process of thermoplastic materials
drying and solvent evaporation and recovery
temperature maintenance of hot water lines

Temperature maintenance requires the application of heat energy to a surface that is equal or greater than the heat loss between the surface and it's surroundings.

Process heating requires the application of heat energy to raise the material or system tempertature or control a chemical reaction.

By a *contant temperature application*, the product or material is kept at a certain temperature regardless of the ambient temperature. The most common applications are frost protection or where products must be maintained at the desired process temperature. Heat loss calculations for this proceedure are based upon "worse case" conditions.

In *process termperature applications* the heat losses are based upon two factors, heat raise and maintenance energy requirements. Heat loss calculations are required for the energy necessary to raise the material and product temperatures to the desired operating temperature over a specific time period and then maintain the temperature as such over a specific cycle time.

Variable process applications involve heat loss calculations based upon the energy necessary for heat raise, temperature maintenance of material or product and safety factor for unknowns.

Safety factor. In many heating applications the actual values for calculation elements or other factors that may effect the process are not known and may only be estimated. For this reason a safety factor, 10% to 40% depending on the design estimation, is recommended in most heat loss calculations to compensate for unknowns. The safety factor is multiplied to the sum of the heat loss calculation.

Required Information for pipeline heat loss calculation

The first step in designing an electrical surface heating system is to determine the heat loss.

For *temperature maintenance heat loss calculation* the following information is necessary:

Dimension, diameter and length of object to be heated
Number of fittings
Number of flanges
Number of supports
Material type
Required maintenance temperature
Minimal ambient temperature
Location Indoor/Outdoor
Insulation material
Insulation thickness
Insulation thermal resistance
Wind speed, if necessary

For *temperature raise heat loss calculation* the following information is necessary in addition to the above mentioned:

Requested final temperature
Requested heat-up time period
Volume or flow quantity
Specific heat of the medium
Specific density of the medium
Weight of the pipe, tank or container

Calculating the heat loss for temperature maintenance of pipelines

Step 1. Calculate the temperature difference (ΔT). This is the difference between the maintenance temperatur (T_m) and the minimal ambient temperature (T_a).

Step 2. Determine the heat loss. Calculations for the heat loss are based upon the form and type of the material, or application.

Step 3. By wind speeds above 32 kmh add a 5% margin for each 8 kmh. The maximal safety margin for wind speed is 10%.

Step 4. Additional safety margins. Multiply any additional safety margings required for unknowns.

Step1. Temperature difference

(ΔT)= maintenance temp. - min. ambient temp

Step 2. Heat loss calculation for insulated pipelines. For each pipeline of different diameter or insulation thickness, a separate heat loss calculation will need to be done. Refer to Table 1.

$$Q = \frac{2 \times \Pi \times \lambda \times \Delta T}{\ln\left(\frac{D_2}{D_1}\right)}$$

λ = Thermal resistance in W/mK
D_2 = Outer diameter with insulation
D_1 = Pipe diameter

For heat losses of the pipline valves please refer to Table2.

Step 3. By wind speeds above 32 kmh add a 5% margin for each 8 kmh. The maximal safety margin for wind speed is 10%.

Step 4. Additional safety margins. Multiply any additional safety margings required for unknowns.

Example 1: The following infromation has been provided by the customer.

Diameter of the pipeline to be heated: DN 25
Material of pipeline: steel.
Length of pipeline: 50m.
Number and type of valves: 2 x Butterfly valves
The required maintenance temperature: 60°C.
The minimal ambient temperature: -10°C
Location: outdoor.
Insulation material: mineral wool.
Insulation thickness: 30mm
Insulation thermal resistance: 0,037 W/mK
Wind speed: 20Kmh
Safety factor: 1,25

1) ΔT = 60°C - (-10°C) = 70K

2) Pipeline Heat Loss

$$Q = \frac{2 \times \Pi \times 0{,}037\ \text{W/mK} \times (70\text{K})}{\ln\left(\frac{0{,}110\text{m}}{0{,}05\text{m}}\right)}$$

Q= 20,6 W/m.

3) Valve heat loss. According to the table 2, factor 0.7

Q = 2 x (20,6 W x 0,7) = 28,84 W

4) The wind speed is less than 32kmh. No additions are necessary.

5) Saftey factor

Q= 20,6 W/m x 1,25 = 25,7 W/m

6) Total heat loss

Q_{total} = (25,7 W/m x 50m) + 28,84W =1313,84 W

Calculating the heat loss for temperature raise of pipelines

Step 1. Calculate the heat loss (without the safety factor) according to the before mentioned instructions "Calculating the heat loss for temperature maintenance".

Step 2. Calculate the heat loss to raise the temperature of the pipeline.

$$Q = \frac{m \times c \times \Delta T}{3{,}6 \text{ Ks/h} \times t}$$

ΔT = Temperatur difference in K
m = weight of material in kg/m
c = specific heat of material in kg/litre
t = time in hours

Step 3. Calculate the heat loss to raise the material inside the pipeline.

$$Q = \frac{V \times \rho \times c \times \Delta T}{3{,}6 \text{ Ks/h} \times t}$$

ΔT = Temperatur difference in K
V = volume in l/m
c = specific heat of material in kg/litre
t = time in hours
ρ = specific density in kg/l

Step 4. Add the values of Steps 1 to 3 together and multipy with the safety factor. This is the total heat loss per meter pipeline.

Example 2: Temperature heat raise

The customer from Example 1 decided that heat raise was necessary and has provided the following additional information.

Requested final temperature: 60°C (from Example 1)
Temperature difference: 70K (from Example 1)
Requested heat-up time period: 4 hours
Weight of pipe: 1,9 kg/m
Specific heat of pipe: 0,49 KJ/kgK
Volume of pipeline: 0,75 l/m
Specific heat of medium: 1,67 KJ/kgK
Specific density of medium: 920 kg/m^3 = 0,92 kg/l

1) The heat loss from Example 1 is 20,6 W/m.

2)
$$Q = \frac{1{,}9 \text{ kg/m} \times 0{,}49 \text{ KJ/kgK} \times 70\text{K}}{3{,}6 \text{ Ks/h} \times 4\text{h}}$$
= 4,52 W/m (J/s=W)

3)
$$Q = \frac{0{,}75\text{l/m} \times 0{,}92 \text{ kg/l} \times 1{,}67 \text{ KJ/kgK} \times 70\text{K}}{3{,}6 \text{ Ks/h} \times 4\text{h}}$$
= 5,6 W/m

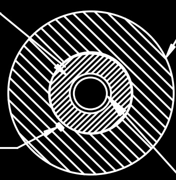
4) Q = 20,6 W/m + 4,52 W/m + 5,6 W/m
= 30,72 W/m

Q_{total} = 30,72 W/m x 1,25
= 38,4 W/m

Calculating heat loss for sandwich insulation

Sometimes the heating cable must be used for higher temperatures than the maximal exposure temperaturer of the heating cable allows. A possible solution for this situation is to use a sandwich (double) insulation. The fist layer is installed onto the pipeline and then covered with a layer of alumimium foil or an intermediate lagging. The cable is then installed and secured using a second layer of aluminium foil or self-adhesive aluminium foil. Afterwards a second layer of insulation is installed and then protected with a cladding.

Two things must be observed when using this method:
1. the first insulation must be rigid
2. the cable is not to be installed on the seam of the first layer of insulation



Calculation of sandwich heat loss:

$$Q = \frac{\text{Maint. temp. - Min. ambient temp.}}{\frac{1}{2\Pi\lambda_1}\ln\left(\frac{D_2}{D_1}\right) + \frac{1}{2\Pi\lambda_2}\ln\left(\frac{D_3}{D_2}\right)}$$

λ_1 = Thermal resistance of inside insulation in W/mK
λ_2 = Thermal resistance of outside insulation in W/mK
D_3 = Outer diameter with inside insulation
D_2 = Outer diameter with outside insulation
D_1 = Pipe diameter

The intermittent temperature between layers may be calculated as follows:

$$T_{exposure} = \left[T_m - \left(T_m + T_a \right) \frac{R_1}{R_1 + R_2} \right]$$

$T_{exposure}$ = cable temperature exposure

T_m = maintenance temperature

T_a = min. ambient temperature

$$R_1 = \frac{1}{2 \Pi \lambda_1} \ln \left(\frac{D_2}{D_1} \right)$$

$$R_2 = \frac{1}{2 \Pi \lambda_2} \ln \left(\frac{D_3}{D_2} \right)$$

λ_1 = Thermal resistance of inside insulation in W/mK
λ_2 = Thermal resistance of outside insulation in W/mK
D_3 = Outer diameter with inside insulation
D_2 = Outer diameter with outside insulation
D_1 = Pipe diameter

Note: in order to determine the maximal exposure temperature of the heating cable a recalculation must be made at the maximal ambient temperature. Repeat the calculation using the maximal ambient temperature in place of "T_a" . A thermostat may be necessary in order to protect the heating cable depending on the maximal exposure temperature and cable type.

Requred information for calculating heat losses of vessels, tanks and hoppers

For *temperature maintenance heat loss calculation* the following information is necessary:

Dimension, diameter and length or surface area of object to be heated
Number and size of supports
Number and size of manways
Number and size of ladders
Type of bottom (dish, spherical, cone, etc.)
Material type
Required maintenance temperature
Minimal ambient temperature
Location Indoor/Outdoor
Insulation material
Insulation thickness
Insulation thermal resistance
Wind speed, if necessary

For *temperature raise heat loss calculation* the following information is necessary in addition to the above mentioned:

Requested final temperature
Requested heat-up time period
Volume or flow quantity
Specific heat of the medium
Specific density of the medium
Weight of the pipe, tank or container

Calculate the heat loss for temperature maintenance of the vessel, tank, or hopper

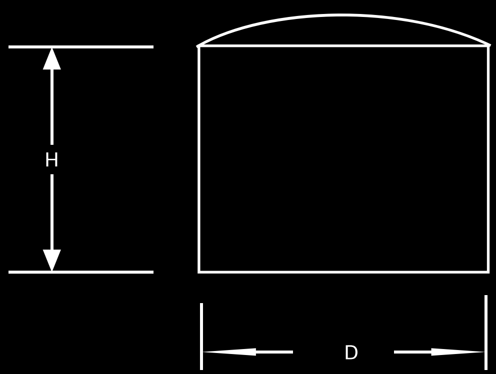
Step 1. Calculate the temperature difference (ΔT). This is the difference between the maintenance temperatur (T_m) and the minimal ambient temperature (T_a).

(ΔT)= maintenance temp. - min. ambient temp

Step 2. Determine the vessel, tank or hopper surface area. Most vessels and tanks have a combination of forms and shapes. Each surface is to be calculated separately and then added together for the total area.

Below are some basic forms with their corresponding equasions:

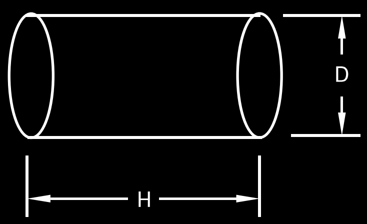
Cylindrical tank with dished top and flat bottom



Area = Top + Cylinder + Bottom

$$= (\pi/4)\,(D^2 + 4h^2) + \pi DH + D^2\pi/4$$

Cylindrical tank with flat ends

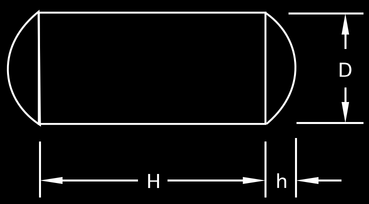


Area = Ends + Cylinder

$$= 2(\pi D^2/4) + \pi DH$$

Volume = $\left[(\pi D^2/4)h \right]$ 1000 dm^3/m^3

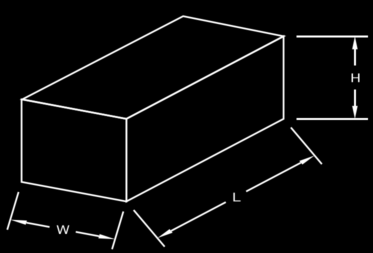
Cylindrical tank with dished ends



Area = Ends + Cylinder

$$= 2\left[(\pi/4)(D^2 + 4h^2) \right] + \pi DH$$

Rectangular vessel

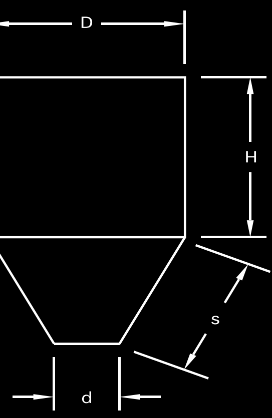


Area = Ends + Sides

$$= 2(WH + HL + WL)$$

Volume = L x W x H

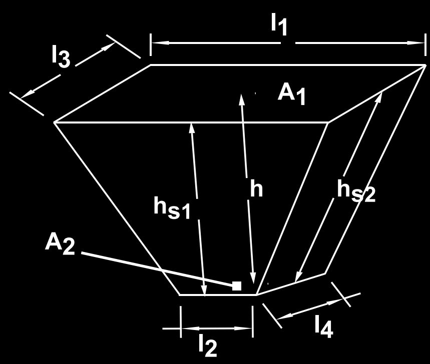
Cylindrical vessel with cone



Area = Top + Side + Cone

$$= \pi D^2/4 + \pi DH + \left[(\pi/2)(D+d)\sqrt{\frac{(D-d)^2}{4} + h^2} \right]$$

Pyramid Hopper



Area = $(l_1 + l_2)h_{s1} + (l_3 + l_4)h_{s2}$

$$hs1 = \sqrt{\frac{(l_3 - l_4)^2}{4} + h^2}$$

$$hs2 = \sqrt{\frac{(l_1 - l_2)^2}{4} + h^2}$$

$$\text{Volume} = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 \times A_2}\right)$$

Step 3. Determine the heat loss for insulated surfaces:

$$Q = A \left(\frac{\Delta T \times \lambda}{D_{iso}} \right)$$

Q = heat loss in W
A = insulated surface area in m^2
ΔT = maint. temp. - min. ambient temp. in K
λ = Thermal resistance in W/mK
D_{iso} = insulation thickness in m

Note: By a cylindrical tank with dished top and flat bottom, the heat loss to the bottom may be determined using the above calculation with:

λ = material thermal resistance in W/mK
D_{iso} = material thickness in m
material = conctrete, tar, earth, etc.

Step 4. Determine the heat loss for uninsulated tank surfaces:

$$Q = A \times R \times \Delta T$$

A = insulated surface area in m^2
ΔT = maint. temp. - min. ambient temp. in K

for heat loss indoors	R= 10 W/m^2K
for heat loss by wind up to 5m/s	R= 30 W/m^2K
for heat loss by wind up to 20m/s	R= 90 W/m^2K

Note: Should the top of the tank surface not be insulated and the tank is not completely filled, the heat loss (with an air thickness of 100mm) to the top may be determined for as follows:

$$Q = A \times 0{,}25\ \mathrm{W/m^2K} \times \Delta T$$

A = insulated surface area in m^2
ΔT = maint. temp. - min. ambient temp. in K

Step 5. Determine the heat loss for supports, manways, and ladders.

for heat loss of support legs
Q= 0,9 W/K x ΔT x number of legs

for heat loss of ladders
Q= 4,5 W/K x ΔT x number of ladders

for heat loss of Manways
Q= 18 W/K x ΔT x number of manways

Step 6: Determine the total heat loss. Add each of the calculated heat losses together and multiply by the safety factor (SF):

$$Q_{total} = \left(Q_{insulated} + Q_{uninsulated} + \ldots \right) SF$$

Example 3: Temperature maintenance heat loss for a cylindrical tank with flat ends.

Tank diameter: 2m
Height of tank: 3m
Position of tank: laying on 3m side
Maintenance temperature: +40°C
Minimal ambient temperature: -10°C
Number of support legs: 3
Insulation thermal resistance: 0,03 W/mK
Thickness of insulation: 80mm
Location: indoor
Safety factor: 25%

$$\Delta T = 40°C - (-10°C) = 50K$$

$$A = 2(\pi\ (2m)^2 / 4) + \pi \times 2m \times 3m$$
$$= 6{,}28m^2 + 18{,}84m^2$$
$$= 25{,}12m^2$$

$$Q_{insulated} = 25{,}12m^2 \left(\frac{50K \times 0.03W/mK}{0{,}08m} \right)$$
$$= 471\ W$$

$$Q_{legs} = 0{,}9\ W/K \times 50K \times 3$$
$$= 135\ W$$

$$Q_{total} = \left(471W + 135W \right) 1{,}25$$
$$= 757{,}5\ W$$

Calculating the heat loss for temperature raise of vessels, tanks, and hoppers

Step 1: Calculate the temperature maintenance heat loss as previously described.

Step 2: Calculate the vessel, tank or hopper volume when not provided by the customer.

Step 3: Determine the heat loss for temperature raise requirements.

$$Q_{raise} = \frac{V\ \rho\ C_p\ \Delta T}{3{,}6 \frac{Ks}{h}\ t}$$

V= volume im litre
ρ = material density in kg/l
C_p= specific heat of material in KJ/kgK
ΔT= maint. temp. - min. ambient temp. in K
t= heat-up time in hours (h)

Step 4: Determine the total heat loss for temperature raise requirements. Add the heat loss for temperature raise requirements and the total surface heat loss of the vessel, tank or hopper together.

$$Q = Q_{total} + Q_{raise}$$

Example 4: Heat loss for temperature raise based upon Example 3. The customer has provided the following information:

fill volume = 8500 litre
ρ = 0,92 kg/l
C_p= 1,67 KJ/kgK
t= 8 hours
Information from Example 3:
ΔT = 50K
Q_{total} = 757,5 W = 0,757 KW

$$Q_{raise} = \frac{8500l \times 0{,}92kg/l \times 1{,}67KJ/kgK \times 50K}{3{,}6\frac{Ks}{h}\ 8}$$

$$= 22{,}67\ KW$$

$$Q = 0{,}757\ KW + 22{,}67\ KW = 23{,}43\ KW$$

Heat loss table and material for in-tank heating

ThermTrace® self-regulating heating cable may be used in order to prevent the separation of wax from the heating oil inside of outdoor heating oil tanks by lower ambient temperatures.

For this application the 25 TTR-2-BOT, termination kits, junction boxes, an ambient thermostat and mounting brackets for the junction box and thermostat, are the only materials necessary.

Below is a table in order to choose which heating cable lengths necessary for up to 500l/h flow rate. Should the flow rate be higher, please contact your local HTS representative.

Volume in litre	Heating cable length in m	Power output @10°C in KW	No. of 16A heating circuit
0...2000	14	0,35	1
5000	22	0,55	1
10000	28	0,7	1
20000	36	0,9	1
40000	56	1,4	1
60000	84	2,2	2
80000	104	2,6	2
100000	120	3,0	2

Note: A 30 mA/100ms residual current device is necessary.

Example 5: A customer is asking for an in-tank heating for a 10000 l heating oil tank.

According to the table the customer will need the following materials:

28 m 25 TTS-2-BOT
1 pc. Termination kit
1 pc. Ambient thermostat with PT100
1 pc. Junction box
2 pc. Mounting brackets, 1 pc. for the thermostat and 1 pc. for the junction box.
1 pc. 16A (type C) circuit breaker
1 pc. 30 mA/100ms residual current device

Installation is to follow in that the heating cable be placed through the tank cover, to the tank bottom and then back out of the tank cover. The heating tape would then be connected to the junction box and afterwards the controller would be connected to the junction box.

Calculating heat loss for flat surfaces

In order to calculate the heat loss for flat surfaces, both sides of the surface area including insulation (installed on both sides) must be taken into account. Should each side not be equally insulated, the heat loss must be determined accordingly and then added together.

$$Q = \frac{\lambda \times A \times \Delta T}{D_{iso}} \times SF$$

A = surface area (top + bottom) in m^2
λ = material thermal resistance in W/mK
ΔT = maint. temp. - min. ambient temp. in K
D_{iso} = material thickness in m
SF = safety factor

Example 6: The customer has requested that a piece of sheet metal be heated.

Dimensions: 500 x 200mm
Insulation: mineral wool 0,035 W/mK
Insulation thickness: 25mm
Temperature difference: 30K
Safety factor: 1,25 (25%)

$$Q = \frac{0{,}035\ W/mK \times 0{,}2m^2 \times 30\ K}{0{,}025m} \times 1{,}25$$

$$Q = 10{,}5\ W$$

Calculating heat loss for temperature raise of flat surfaces

To determine the heating power necessary for heat raise of flat surfaces, determine the insulated surface heat loss as in example 6 without and add this to the material heat-up requirement.

$$Q_{raise} = \frac{m \times A \times C_p \times \Delta T}{3{,}6\ Ks/h \times t}$$

ΔT = Temperatur difference in K
A = surface area in dm^3
m = weight of material in kg/dm^3
C_p = specific heat of material in KJ/kgK
t = time in hours

Example 7: The additional information has been provided as follows.

Type of material: Steel
m = 7,85 kg/dm^3
C_p = 0,49 KJ/kgK
t = 2 hours
ΔT = 30 K
dimensions = 5 dm x 2 dm
material thickness: 0,03 dm

A = 10 dm x 2 dm x 0,03 dm
= 0,3 dm^3

$$Q_{raise} = \frac{7{,}85\ kg/dm^3 \times 0{,}6dm^3 \times 0{,}49KJ/kgK \times 30K}{3{,}6\ Ks/h \times 2}$$

= 69,24 W

Heat loss from example 6 without safety factor

Q = 10,5 W

Qtotal = Q + Q_{raise}
= 69,2W + 4,8W
= 74W

Heating cable selection

In order to determine the correct heating tape or cable according to the application the following infromation will be necessary:

Maintenance temperature
Max. exposure temperature
Pipe or surface material
Supply voltage
Chemical environment
Area classification
Heat requirement

Maintenance temperature: this is the temperature at which the surface temperature is to be maintained in order to kept the product or material at a certain temperature regardless of the ambient temperature.

Maximum exposure temperature: this is the maximum temperature that may occur during a certain process, such as the vessel filling temperature or when steam is used to clean the pipeline.

Pipe or surface material: the surface material is an important factor as to the design of electrical trace heating, such as the installation of aluminium foil onto the surface before installing the heating cable to a plastic type surface.

Supply voltage: used to determine the type of cable or installation of the cable according to the supplied power, such as self-limiting heating cable by 230V or PTFE cable in delta by 430V.

Chemical environment: used to determine the type of heating cable or tape construction, such as for chemical or domestic environments.

Area classification: not all heating cables or tapes are approved for Ex areas or all of their conditions, such as temperature or gas classification.

Heat requirement: selection of the heating cable or tape is based upon the power output at a certain ambient or maintenance temperature.

Select the appropriate heating cable/tape from our product catalogue based upon the maximum exposure temperature, maintenance temperature and area classification.