SIMPLE HEAT EXCHANGER SIZING CALCULATOR

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Contents

Introduction

This document describes the basis and operation of the Blackmonk Engineering Heat Exchanger Sizing Calculator.

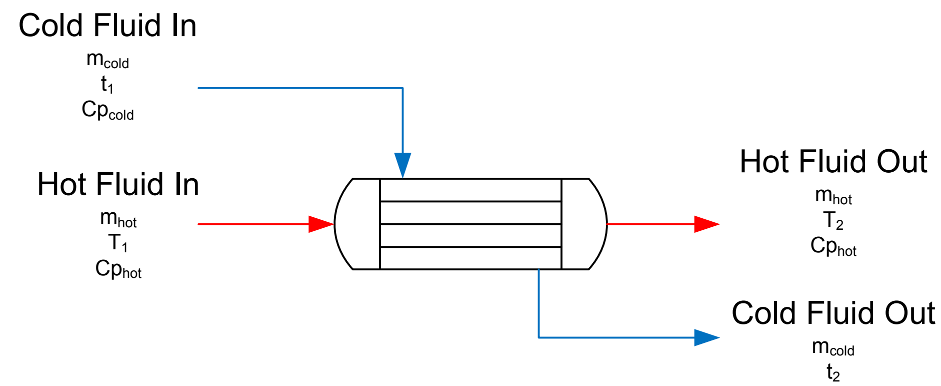
The calculation methodology is based on that described in “Process Heat Transfer”, D.Q. Kern and “Chemical Engineering Volume 6 – Design”, Coulson & Richardson.

The calculator determines the heat transfer area required for a simple heat exchanger. Hot stream flow rate, hot and cold stream inlet and outlet temperatures and heat capacities and the overall heat transfer coefficient are required as inputs. The heat exchanger arrangement may be counter-current, co-current or mixed. The mixed arrangement is for a 1 shell:2 tube-side pass exchanger but is applicable to any exchanger with an even number of tube-side passes.

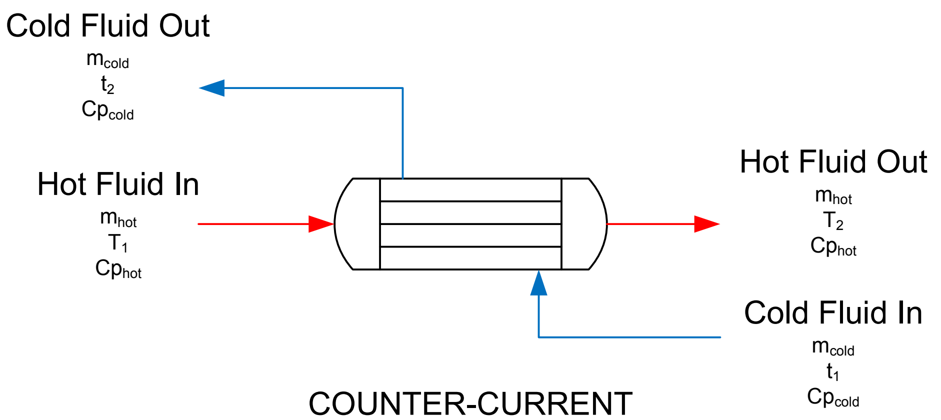
The calculator determines the heat exchanger duty, cold stream flow rate and relevant temperature differences including correction factors where appropriate.

The calculator is applicable to heat exchangers with no phase change in either the hot stream or cold stream and where the stream heat capacities can be taken as constant through the exchanger.

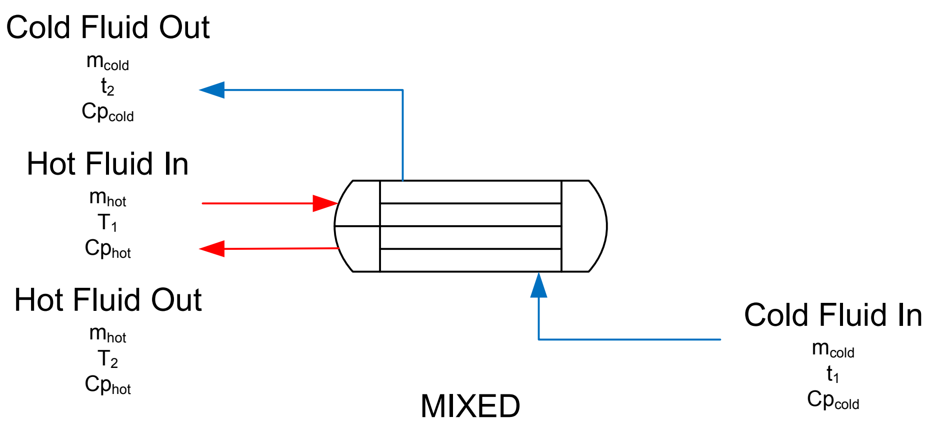
System Diagram



CO-CURRENT



COUNTER-CURRENT



MIXED

Calculation Inputs

The following parameters are user specified inputs to the calculation:

Input	Description	Units
Hot stream flow rate	Mandatory user specified hot stream flow rate	kg/hr
Hot fluid inlet temperature	Mandatory user specified hot stream inlet temperature	C
Hot fluid outlet temperature	Mandatory user specified hot stream outlet temperature	C
Cold fluid inlet temperature	Mandatory user specified cold stream inlet temperature	C
Cold fluid outlet temperature	Mandatory user specified cold stream outlet temperature	C
Hot fluid specific heat capacity	Mandatory user specified hot stream specific heat capacity	kJ/(kg.K)
Cold fluid specific heat capacity	Mandatory user specified cold stream specific heat capacity	kJ/(kg.K)
Overall heat transfer coefficient	Mandatory user specified overall heat transfer coefficient	W/(m^2.K)
Heat exchanger type	Mandatory user specified heat exchanger type – selected from co-current, counter-current and mixed	N/A

Calculation Outputs

The following parameters are calculated by the software and displayed to the user:

Output	Description	Units
Heat exchanger duty	Total heat transferred from hot fluid to cold fluid	kW
Cold stream flow rate	Calculated required flow rate of cold fluid to meet heat exchanger duty	kg/hr
Terminal temperature difference 1	Temperature difference between the hot and cold streams at the hot stream inlet node	K
Terminal temperature difference 2	Temperature difference between the hot and cold streams at the hot stream outlet node	K
Mean temperature difference	Mean temperature difference between the hot and cold fluids across the heat exchanger. The mean temperature difference is the log mean temperature difference unless the terminal temperature differences are equal. In this case the mean temperature difference is the arithmetic mean temperature difference	K
R factor	Heat capacity rate ratio	N/A
S factor	Temperature ratio	N/A
LMTD correction factor	Correction factor applied to mixed flow type heat exchanger mean temperature difference	N/A

Effective mean temperature difference	Product of mean temperature difference and LMTD correction factor	K
Heat transfer area required	Calculated heat transfer area required to achieve the calculated heat exchanger duty	m^2

Heat Exchanger Heat Transfer

A heat exchanger transfers heat from a hotter fluid to a colder fluid across a heat transfer surface. The heat exchanger duty can be calculated using the following relationship:

$$Q = UAF\Delta T_M \qquad \textbf{Equation 1}$$

Where ΔT_M is the mean temperature difference between the hot fluid and the cold fluid through the heat exchanger.

Mean Temperature Difference

The mean temperature difference used in Equation 1 is generally the log mean temperature difference. The log mean temperature difference is calculated using the terminal temperature differences in the following equation:

$$\Delta T_M = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \qquad \textbf{Equation 2}$$

In the event that the terminal temperature differences are equal, the mean temperature difference is defined as the terminal temperature difference:

$$\Delta T_M = \Delta T_1 \qquad \textbf{Equation 3}$$

Terminal Temperature Differences

ΔT_1 and ΔT_2 are the terminal temperature differences at the hot stream inlet and hot stream outlet respectively.

In a co-current heat exchanger, ΔT_1 is equivalent to the temperature difference between the hot stream inlet temperature and the cold stream inlet temperature. ΔT_2 is equivalent to the temperature difference between the hot stream outlet temperature and the cold stream outlet temperature.

In a counter-current heat exchanger, ΔT_1 is equivalent to the temperature difference between the hot stream inlet temperature and the cold stream outlet temperature. ΔT_2 is equivalent to the temperature difference between the hot stream outlet temperature and the cold stream inlet temperature.

In a mixed type heat exchanger, the terminal temperature differences are defined as for a counter-current exchanger.

The terminal temperature differences for each type of exchanger are summarised in Table 1.

Table 1: Terminal Temperature Differences

Heat Exchanger Type	ΔT_1	ΔT_2
Co-current	$T_1 - t_1$	$T_2 - t_2$
Counter-current	$T_1 - t_2$	$T_2 - t_1$
Mixed	$T_1 - t_2$	$T_2 - t_1$

Mixed Flow Heat Exchanger Temperature Correction Factor

Mixed flow heat exchangers are effectively a combination of a co-current and counter-current exchanger. For part of the flow path, the fluids are co-current and for another part of the flow path, the fluids are counter-current.

The mean temperature difference in a mixed flow heat exchanger is therefore intermediate between co-current and counter-current flow. The most common method of estimating the true mean temperature difference in a mixed flow heat exchanger is to use a temperature correction factor to modify the counter-current mean temperature difference.

The temperature correction factor for a 1 shell-side:2 tube-side heat exchanger is determined from the following equation [Ref: "Chemical Engineering Volume 6 – Design" Coulson & Richardson 2^{nd} Ed. Pg. 586]:

$$F = \frac{\left(R^2+1\right)^{0.5} \ln\left[\frac{(1-S)}{(1-RS)}\right]}{(R-1)\ln\left[\frac{2-S\left[R+1-\left(R^2+1\right)^{0.5}\right]}{2-S\left[R+1+\left(R^2+1\right)^{0.5}\right]}\right]}$$

Equation 4

Where

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$

Equation 5

$$S = \frac{t_2 - t_1}{T_1 - t_1}$$

Equation 6

This correction factor can also be used for any heat exchanger with an even number of tube passes.

For co-current or counter-current heat exchangers, the temperature correction factor is 1.

Effective Mean Temperature

The calculator determines the effective mean temperature difference based on the following equation:

$$\Delta T_{Meff} = F\Delta T_M$$ **Equation 7**

Heat Exchanger Heat Balance

The heat balance defining the heat transfer from the hot stream to the cold stream for a simple heat exchanger is given by the following relationship:

$$m_{hot}Cp_{hot}(T_1 - T_2) = m_{cold}Cp_{cold}(t_2 - t_1)$$ **Equation 8**

The heat exchanger duty can be defined in terms of specified inputs by:

$$Q = m_{hot}Cp_{hot}(T_1 - T_2)$$ **Equation 9**

Calculation of Heat Transfer Area

The required heat transfer area is determined from the specified hot stream flow rate, hot and cold stream inlet and outlet temperatures, fluid specific heat capacities, heat exchanger type and the overall heat transfer coefficient.

The calculation routine is described in the following steps:

1. Calculate the heat exchanger duty using Equation 9
2. Calculate the cold stream flow rate using Equation 8
3. Calculate the terminal temperature differences using Table 3
4. Calculate the mean temperature difference using Equation 2 or Equation 3 if the terminal temperature differences are equal
5. Calculate R using Equation 5
6. Calculate S using Equation 6
7. Calculate the temperature correction factor, F using Equation 4 if the heat exchanger is a mixed flow type
8. Calculate the effective mean temperature difference using Equation 7
9. Calculate the required heat transfer area using Equation 1

Nomenclature

m_{hot} = Flow rate of hot stream (kg.s^{-1})
m_{cold} = Flow rate of cold stream (kg.s^{-1})
T_1 = Hot stream inlet temperature (C)
T_2 = Hot stream outlet temperature (C)
t_1 = Cold stream inlet temperature (C)
t_2 = Cold stream outlet temperature (C)
Cp_{hot} = Hot stream specific heat capacity (J/(kg.K))
Cp_{colt} = Cold stream specific heat capacity (J/(kg.K))
U = Overall heat transfer coefficient (W/(m^2.K)
Q = Heat exchanger duty (W)
ΔT_1 = Terminal temperature difference 1 (K)
ΔT_2 = Terminal temperature difference 2 (K)
ΔT_M = Mean temperature difference (K)
ΔT_{Meff} = Effective mean temperature difference (K)
F = Temperature correction factor (dimensionless)
R = Heat capacity rate ratio (dimensionless)
S = Temperature ratio (dimensionless)
A = Heat transfer area (m^2)

Example

The following example was taken from "Chemical Engineering Volume 6 – Design" Coulson & Richardson Example 12.1 page 603.

Description:

Design a 1 shell pass, 2 tube pass heat exchanger to sub-cool condensate from a methanol condenser from 95C to 40C. Flow rate of methanol 100,000 kg/hr. Brackish water will be used as the coolant with a temperature rise from 25C to 40C.

Methanol specific heat capacity = 2.84 kJ/(kg.K)
Water specific heat capacity = 4.2 kJ/(kg.K)

Requirement:

Find the heat exchanger duty, flow rate of water required and the heat transfer area.

Solution:

Heat exchanger duty = 4339 kW (cf: C&R Vol 6 published result of 4340 kW)

Cooling water flow rate = 247937 kg/hr (68.9 kg/s) (cf: C&R Vol 6 published result of 68.9 kg/s)

Heat transfer area = 289.2 m^2 (cf: C&R Vol 6 published result of 278 m^2)

The difference in calculated heat transfer areas is due to the difference in temperature correction factors used. The calculator determines the correction factor as 0.812 from Equation 4 whereas C&R Vol 6 uses an approximate value of 0.85 obtained from a temperature correction factor chart.

Simple Heat Exchanger Sizing Calculator Screenshot:

INPUTS

Hot stream flow rate	m_{hot}	100000.0	kg/hr
Hot fluid inlet temperature	T_{in}	95	C
Hot fluid outlet temperature	T_{out}	40	C
Cold fluid inlet temperature	t_{in}	25	C
Cold fluid outlet temperature	t_{out}	40	C
Hot fluid specific heat capacity	Cp_{hot}	2.84	kJ/(kg.K)
Cold fluid specific heat capacity	Cp_{cold}	4.2	kJ/(kg.K)
Overall heat transfer coefficient	U	600	W/(m2.K)
Heat exchanger type		Mixed	

OUTPUTS

Heat exchanger duty	Q	4338.889	kW
Cold stream flow rate	m_{cold}	247936.5	kg/hr
Terminal temperature difference 1	ΔT_1	55.0	K
Terminal temperature difference 2	ΔT_2	15.0	K
Mean temperature difference	ΔT_M	30.8	K
R factor	R	3.6667	
S factor	S	0.2143	
LMTD correction factor	F	0.812	
Effective mean temperature difference	ΔT_{Meff}	25.0	K
Heat transfer area required	**A**	**289.2**	**m2**