Airec Technical Handbook - Heat exchanger types, selection and applications

Summary
A guideline on how to design the optimal Airec heat exchanger for the intended application. The handbook also addresses which parameters and possible risks that should be considered in the design phase in order to prevent failures.
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1. **Heat Exchanger Selection**

Airec develop and manufacture highly efficient **brazed stainless steel plate heat exchangers**. We focus on applications where standard products commonly available on the market do not completely meet the customer’s needs. Airec products typically provides lower pressure drops, increased compactness, higher efficiency and condensation, wider operating temperature ranges, and reduced cost. Applications where Airecs products are suitable usually have several of the following requirements:

- An asymmetry between the fluids volume flows \( \geq 1:10 \) (e.g. gas-to-coolant heat transfer)
- Able to handle gas temperatures in the span \( 25 - 700 \, ^\circ C \)
- Temperature efficiency, \( \eta > 80 \% \)
- Low pressure drop for the high volume flow fluid, \( \Delta P = 0.05 - 2 \, kPa \)
- Heat exchanger manufactured in stainless steel
- Absolute pressure on the high pressure side of \( 2 - 25 \, \text{bar(a)} \) combined with a pressure of \( 1 - 3 \, \text{bar(a)} \) on the low pressure side
- High condensation

Applications were the heat transfer is liquid-to-liquid, gas-to-gas, or air-to-air can normally be handled by standard heat exchangers, which Airecs products in most cases are not price competitive against.

**A. Airec HEX Families**

An Airec heat exchanger is made by vacuum brazing a stack of stamped heat exchanging plates together with either copper or nickel as the brazing material. Each of the plates in the stack has a patented pattern of dimples, where the void between the brazed plates forms channels for the fluids. The voids have different volume depending on which fluid is supposed to flow through them:

- **Side A** – narrower channels for the low volume coolant flow, this side is designed to be the high pressure side of the heat exchanger.
- **Side B** – larger volume channels for the gaseous flow, the high temperature side.

Airec has two major product families, **Compact** and **Cross**. Figure 1 shows both families, the heat exchangers in the foreground belongs to the Compact family, the forth heat exchanger with an open gas side is a Cross. The main differences are tabulated in table 1.
Figure 1. Airec product families – Compact and Cross

Table 1. Airec Heat Exchanger Families

<table>
<thead>
<tr>
<th>Family</th>
<th>Connections</th>
<th>Need External Casing</th>
<th>System integration</th>
<th>Cleaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact</td>
<td>All integrated in end plates</td>
<td>No</td>
<td>“Limited”</td>
<td>Both circuits - CIP</td>
</tr>
<tr>
<td>Cross</td>
<td>Coolant connections on top plate</td>
<td>Yes</td>
<td>Large HEX area</td>
<td>Side A – CIP</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“Dirty” gases</td>
<td>Side B – High pressure washer from external hatch</td>
</tr>
</tbody>
</table>
B. Installation of AirecCalc

*From the AirecCalc V1.3R User Manual:*

<table>
<thead>
<tr>
<th>You will always need a new license in following cases to be able to run AirecCalc:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- You are new user and install AirecCalc for the first time</td>
</tr>
<tr>
<td>- Want to install AirecCalc on the new computer</td>
</tr>
</tbody>
</table>

**Please Note!**

- License is unique for each computer
- License is valid for 12 months
- Contact AIREC at info@ airec.com for renewal of license

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**How to install the program and gets the license (F.O.C.) for the first time or for reinstallation.**

1. Double click the on the installation “setup.exe” file
2. Follow the setup instructions on the screen.
3. Installation is done. Find the AirecCalc icon on your desktop, double click on the icon.
4. Following screen will appear: “AirecCalc – License Key Activator” (see image below).
5. **[Generate key root]:** Click on this button and you will generate the key root file “keyroot.krf”.*
6. *Send this file “keyroot.krf” with your name, company, address, and e-mail to: info@airec.com
7. When you receive the license key file “Licensekey.lck”. Save it to your computer.
8. **[Install license key]:** Click on this button to install the “Licensekey.lck” (see image below)

*If you have problem during installation do not hesitate to contact us at: info@airec.com

---

![AirecCalc - License Key Activator](image.png)
C. **HEX Performance Calculations**

Airec has developed a software for calculations on performance of our heat exchangers called AirecCalc. In this program you are able to do calculations for most of the applications that Airec heat exchangers can be used in.

When you start the software you will open the window shown in figure 2. This is the main window for the software, this is where you perform calculations. Note that it is possible to have several of these windows open at the same time.

![AirecCalc calculation window](image)

AirecCalc starts per default in the “design”-mode, both this mode and the “Design Wizard” are most suited for calculations on Cross 30. Since it often is better to use a Compact heat exchanger for an application is this guide focused on working in the “rate”-mode. You alter the calculation mode by choosing “Rate heat exchanger” in the calculation settings, see figure 3. In the “Module” menu below you are able to choose the heat exchanger model you would like to use. A good practice is to always choose the maximum number of plates for the first calculation. The result will then tell you if the model choice was correct or not.
Figure 3. Where to alter the calculation mode and set the type of heat exchanger to perform the calculation on.

Figure 4 shows the upper part of the in-data part of the calculation window. To perform a calculation, start by setting heat transfer type on side B, the gas side (phase changes are not permitted on side A). Choose your fluids on each side from the available options (if the fluid is not available, choose a similar or submit a request to Airec for a new media, see section 1.C.2 for details). Set the absolute pressures for the fluids. Note that you can choose the pressure unit you prefer in the roll menu.

Figure 4. The upper part of the in-data part of the calculation window.

The flow rate and the temperature of the gas is usually known, the values of these should be entered in the design boxes, see figure 5. You can set your preferred unit for flow rate and temperature in the individual roll menus. Note that in rate mode are only the flow rate and temperature of the coolant and gas needed to perform the calculation. Commonly you know the temperature of the coolant and the maximum available flow rate of the coolant. You can enter these as start values and optimize the coolant flow rate from the results of the calculation.
Figure 5. The design boxes in the calculation window

Perform the calculation by clicking “Run calculations” in the quick command bar shown in figure 6.

Figure 6. The quick command bar.

Figure 7 shows an example of the results from a calculation, in this case hot, moist air cooled with water. Notice that you are able to calculate with fouling. Enter the percent of area reduction in the box for “Fouling factor”. You are able to choose your preferred unit for the pressure drops and the heat transferred by using the individual roll menus.

Figure 7. Results for calculation of 150 °C moist air (10 % RH) cooled with 10 °C water.

An AirecCalc report of the results can be generated by clicking “Report” in the quick command bar. A new window, as the one shown in figure 8, with the report will open. The report is available in two different layouts, standard (one page) and advanced (three pages). Under “File” can the report be saved or transferred to Word, Excel, pdf, or text format.
In the bottom right corner of the AirecCalc calculation window (see figure 2) is an information box. This box will get a green, yellow or red coloured frame when a calculation is performed, examples of this is shown in figure 9. Heat transfer calculations are quite complex, there are several different parameters to consider. These frames are there to help the user to validate the performed calculation in the following manner:

- **Green frame:** The calculation was performed without any warnings. There might still be a better solution to be found, but there is nothing in the data used or in the results which need your attention.

- **Yellow frame:** The calculation was performed but you should be aware that at least one parameter in the calculation might need your attention. Information on what it is that needs your attention is given by the warning string shown in the information box. The seriousness ranges from the harmless “No condensation occurs” to the critical “CAUTION: BOILING RISK (WATER)!”

- **Red frame:** The calculation was not performed. One of four things have occurred; most common – the pressure drop in one or both channels is larger than the fluids in-pressure, the second is then the energy balances in the calculation algorithm are unbalanced, the third occurs when the number of calculations made reach the max limit and the last one occurs when there is a bug in the program.
Figure 9. Examples of the information box with different frames.
1. Heat Transfer Type

In AirecCalc are the fluids represented by a file, called media, which contains the fluids thermophysical properties for a specified temperature interval. The media are divided into three categories depending on the phase behaviour during the heat transfer:

- **Single Phase** – *The fluid physical state remains unchanged during the heat transfer.*
- **Gas with Condensable** – *Part of the fluid mixture condensate during the heat transfer.*
- **Two Phase** – *All or part of the fluid changes phase during the heat transfer.*

Most of the standard heat transfer applications can be calculated in AirecCalc. There are some exceptions, when it is better to ask Airec to perform the calculations. Table 2 shows these exceptions. Please note that you are always welcome to ask Airec to perform calculations.

*Table 2. When to use AirecCalc.*

<table>
<thead>
<tr>
<th>Type</th>
<th>Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Phase</td>
<td>AirecCalc</td>
</tr>
<tr>
<td>Gas with Condensable</td>
<td>AirecCalc</td>
</tr>
<tr>
<td><strong>Two Phase:</strong></td>
<td></td>
</tr>
<tr>
<td>Condensation Pure Fluid</td>
<td>AirecCalc</td>
</tr>
<tr>
<td>Evaporation Pure Fluid</td>
<td>Ask Airec</td>
</tr>
<tr>
<td>Complex Condensation/Evaporation</td>
<td>Ask Airec</td>
</tr>
</tbody>
</table>

2. Medias

AirecCalc comes equipped with a standard library of fluids/media. These covers most of the standard applications where Airec heat exchangers are suitable, but sometimes is the application’s media not available in the standard library. In such a case you need to contact Airec sales department and ask for the media. If the relevant data can be found will the requested media be generated and sent to you. To speed up the generation process, provide Airec with as much of the data described for each media below as possible.

To import a new media you start by entering your media database, which you find under the Windows menu, see figure 10.

*Figure 10. The window menu.*
By clicking the media database, a pop-up window as the one shown in figure 11 will appear. In this window you can import the new media to the database by clicking on the folder icon and import the media file from where you have stored it on your computer (e.g. desktop, downloaded files, etc.). A new media will by default get “(Imported)” added to the name, you can delete this and re-save the media if you want.

Figure 11. Media Database pop-up window. The folder icon for import of new media is encircled.
a) **Single Phase**

The first thing we need to know to generate a single phase media is if it is a liquid or a gas. Secondly we need the information shown in table 3. Please note that if the media is a gas, the values must be for a gas at 1 bar absolute pressure\(^1\). The requested properties of the fluid should be given for at least four different temperatures. For the most accurate results of the calculations should one of the temperature be below the operational temperature span and one above the operational temperature span. If your data are in units other than the specified, send them as is, it is always best to get as original data as possible.

Table 3. Data needed to generate a single phase media. These data is also needed for generation of “Gas with Condensable” media.

<table>
<thead>
<tr>
<th>Temperature [^\circ C]</th>
<th>Density [kg/m(^3)]</th>
<th>Dynamic Viscosity [Paˑs]</th>
<th>Thermal Conductivity [W/(Kˑm)]</th>
<th>Specific Heat [J/(Kˑkg)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T_1 - 5 \circ C, T_1 = \text{lower limit of operational span})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(T_2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(T_3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(T_4 + 5 \circ C, T_4 = \text{upper limit of operational span})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) **Gas with Condensable**

As the name says are these fluids a gas which carries a condensable vapour, e.g. moisture in air, water in exhaust, acetone in nitrogen, etc. Therefore, we need, at least, information on the initial gas composition to be able to create these media. Further, we need information both about the condensing compound and the gas. The gas is treated as a single phase media by the software, therefore should values in table 3 be provided. For the condensing compound we need the thermal behaviour of the enthalpy of vaporization and the vapour pressure, preferably as temperature dependent formulas, e.g.:

\[
\Delta H_{vap} = A \left(1 - \frac{T}{T_c}\right)^n
\]

\[
\log_{10} P = A + \frac{B}{T} + C \log_{10} T + DT + ET^2
\]

\(^1\) AirecCalc treats single phase media as ideal fluids, this means as incompressible liquid or ideal gas.
c) **Two Phase**

Calculations on total or partial condensation of a pure gaseous fluid is possible in AirecCalc. We need quite a lot of information to create media for two phase (phase transition) heat transfer calculations. Critical properties and formula constants for the thermophysical liquid and vapour behaviour of the substance needed to create the media are listed below.

**Values:**

- Critical Pressure: \([\text{bar}]\)
- Critical Temperature: \([\text{Kelvin}]\)
- Molecular Weight: \([\text{g/mol}]\)
- Acentric Factor: \([-\] \]

**Formula constants or tabulated values:**

To create a two phase media Airec need formulas, with constants, describing the thermal behaviour of the following properties (unit used in AirecCalc inside bracket), the exact formulas used in AirecCalc are shown in appendix B. If the formulas cannot be provided, tabulated values of the thermal behaviour of the property at 1 bar pressure should be provided (atmospheric pressure will also do), to be used for re-calculation by Airec. If possible please also provide the temperature span the formulas are valid for.

- Enthalpy of Vaporisation: \([\text{kJ/mol}]\)
- Liquid Density: \([\text{g/ml}]\)
- Liquid Viscosity: \([\text{centipoise}]\)
- Liquid Thermal Conductivity: \([\text{W/(mˑK)}]\)
- Liquid Specific Heat: \([\text{J/(molˑK)}]\)

- Vapour Pressure: \([\text{mmHg}]\)
- Vapour Viscosity: \([\text{micropoise}]\)
- Vapour Thermal Conductivity: \([\text{W/(mˑK)}]\)
- Vapour Specific Heat: \([\text{J/(molˑK)}]\)
3. HEX Configuration

It is not always possible to achieve the intended heat transfer with a single heat exchanger. You may be restricted by e.g. the pressure drops, insufficient condensation, etc. The solution is to use an additional number of heat exchangers. Depending on how you place the heat exchangers versus the two entering flows you will get different results. To be able to calculate the effect of adding additional heat exchangers in AirecCalc, the “Module assembly” box has been integrated, see figure 12. Here you can, besides changing the flow direction of the coolant from counter- to co-current, change the number of heat exchanger in the calculation by altering the numbers in the four fields. If you alter the number of heat exchangers in more than one field, the total number of heat exchangers will be those numbers multiplied. In the next sections are the effect of altering the number in each field described. Please note that the three lowest fields also can be used as adding additional passages in the Compact family heat exchangers, more details in the next sections.

![Module assembly](image)

*Figure 12. The “Module assembly” box in AirecCalc.*

a) **Flow Division, FD**

This field divide the side B flow to the number of heat exchangers you entered. This will result in a lower pressure drop on side B.

b) **Number of Steps, NS**

To reach the required performance and/or condensation are sometimes additional “thermal length” needed. This can be achieved by letting the fluids run through two or several sequential heat exchangers. NS stacks the entered number of heat exchangers upon each other. The increased performance comes at the cost of increased pressure drops. *Compact:* NS corresponds to internal passages with both fluids in countercurrent/concurrent flow. Please note that when the total plate number exceeds the maximum plate number of the Compact version, it corresponds to two or more heat exchanger units with internal passages in sequel.
c) **Parallel on side A, PA**
Parallel flow of the coolant can be used to lower the pressure drop on side A. PA should be used with care, this configuration usually increases the boiling risk for the coolant, see section 2.F.3. Compact: PA corresponds to internal passages for side B only.

d) **Parallel on side B, PB**
Parallel gas flow can be used to increase the pressure drop on side A and thereby secure a better distribution of the coolant in all the side A channels. Compact: PB corresponds to internal passages for side A only.

e) **Counter Flow / Concurrent flow**
In flow configuration roll menu the preferred coolant flow direction, countercurrent or concurrent, can be chosen. The benefits of each of the two flow regimes are given in table 4.

*Table 4. The benefits of countercurrent respective concurrent flow.*

<table>
<thead>
<tr>
<th>Countercurrent Flow</th>
<th>Concurrent Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>More efficient heat transfer</strong></td>
<td><strong>Very efficient cooling at the gas inlet, good option when the plate material tend to become overheated</strong></td>
</tr>
<tr>
<td><strong>It is possible to cool a gas stream to a temperature close to the inlet temperature of the coolant</strong></td>
<td><strong>Since the outgoing temperatures of the gas and the coolant are nearly equal is this advantageous there is an upper temperature limit for the coolants temperature</strong></td>
</tr>
<tr>
<td><strong>Uniform heat transfer in the whole heat exchanger</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Uniform temperature difference over the heat exchanging plates in the heat exchanger minimizes the thermal stresses</strong></td>
<td></td>
</tr>
</tbody>
</table>
4. Application Design Parameters

To be able to perform a heat transfer calculation in AirecCalc you basically only need to know which fluids, their pressures, their flow rates, and their entering temperatures. The trick is to find a suitable heat exchanger to the customer’s application from these figures. Often additional information such as maximum pressure drops, the available re-cooling of the coolant, maximum/minimum coolant flow rate and other limiting factors has to be known to optimize the selection.

a) Flow Rates and $\Delta P$

Adding a heat recovery unit to a process line will of course give raise to additional pressure drop. In fact a certain pressure drop is needed to ensure a good heat transfer. Different applications can allow different size of this pressure drop due to the available pump capacity. Typical gaseous pressure drops (Side B) for typical asymmetric applications are given in table 5. To lower the pressure drop, on the gas side, there are three options; increase the number of plates, use a larger heat exchanger model or divide the flow onto several heat exchangers (use FD in module assembly). A short description on how the pressure drop is related to the flow speed is given below.

A relative high pressure drop on the coolant side, side A, is needed to avoid maldistribution of the coolant. The risk of maldistribution increases with increasing plate number in the heat exchanger. To avoid issues with maldistribution of the coolant, the side A pressure drop should be substantial larger than the side B pressure drop.

<table>
<thead>
<tr>
<th>Application</th>
<th>Typical pressure drop (gas side) [mbar]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHP exhausts</td>
<td>4 - 15</td>
</tr>
<tr>
<td>Heat recovery from Gas</td>
<td>1 - 10</td>
</tr>
<tr>
<td>Intercooler</td>
<td>5 - 20</td>
</tr>
<tr>
<td>Aftercooler</td>
<td>1 - 60</td>
</tr>
<tr>
<td>Process condensation</td>
<td>3 - 30</td>
</tr>
<tr>
<td>Low pressure steam</td>
<td>0.5 - 5</td>
</tr>
<tr>
<td>Vacuum systems</td>
<td>0.2 - 2</td>
</tr>
</tbody>
</table>

The pressure drop in a heat exchanger is proportional to the mass flow. Therefore will an increased mass flow into a heat exchanger result in an increased pressure drop. A fluid that is forced to run through an enclosed area will lose some of its pressure due to friction, this is usually referred to as the pressure drop. The size of the loss can be calculated using Bernoulli’s equation, in this case the expression can be shortened to:

$$\Delta P = K_{fricton} \cdot \frac{\rho_{fluid}}{2} \cdot \left( \frac{\dot{m}_{fluid}}{Area_{cross-section} \cdot \rho_{fluid}} \right)^2$$
Where $\Delta P$ is the pressure drop, $K$ a friction factor, $\rho$ the density of the fluid, and $\dot{m}$ the mass flow of the fluid. The friction factor is geometry dependent, a smooth round geometry gives a lower friction than a rough square geometry.

In an Airec heat exchanger there are three different contributions to the pressure drop (change of cross sectional area results in a pressure drop-off resistance). The three contributions are; the entry port, the fluid passage and the outlet port. The total pressure drop is given by:

$$\Delta P_{\text{Total}} = (\xi_{\text{expansion}} + \xi_{\text{contraction}}) \cdot \frac{\rho_{\text{fluid}} \left( \frac{\dot{m}_{\text{fluid}}}{\text{Area}_{\text{cross-section}}} \rho_{\text{fluid}} \right)^2}{2} + (4f \cdot \frac{L}{D_h}) \cdot \frac{\rho_{\text{fluid}} \left( \frac{\dot{m}_{\text{fluid}}}{\text{Area}_{\text{cross-section}}} \rho_{\text{fluid}} \cdot n_{\text{channel}} \right)^2}{2}$$

Where $\xi$ is the friction factor for expansion and contraction, $f$ the Fanning friction factor, $L$ the length between the ports, $D_h$ the hydraulic diameter of the channel, and $n$, the number of channels in the heat exchanger.

### b) Thermal Load and Temperature

Airec heat exchangers are designed to handle relative high gas temperatures, ca. 650 -700 ºC. Above these gas temperatures can high temperature corrosion and other high temperature effects occur. The critical factors are the temperature of the coolant and the coolant flow rate. It is important that the heat exchanging plates have sufficient and uniform cooling during operation. If this are fulfilled Airec heat exchangers can handle plate temperatures up to 190 ºC. Therefore should you avoid applications with low coolant flow and high plate temperature, the risk of thermal fatigue (see section 2.F.1) is too high. Note that both too low flow and too high flow can give issues with maldistribution of the fluids in the heat exchanger.

### c) Sizing

The main purpose of AireCalc is to help the user to find the correct heat exchanger model and size to fulfil the task at hand. The choice of heat exchanger model is governed by the gas flow and the allowed pressure drop in the application. Table 6 shows the general guideline for the suitable model at different gas flows. Please note that there are overlaps between the different models, one should compare the results with a larger model when a size of 60 plates is needed for compact 25/36.

<table>
<thead>
<tr>
<th>Compact</th>
<th>25 [kg/h]</th>
<th>36 [Nm³/h]</th>
<th>71 [kg/h]</th>
<th>1200 [Nm³/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>500</td>
<td>500</td>
<td>2000</td>
<td>12000</td>
</tr>
</tbody>
</table>

Table 6. General guidelines for the suitable Compact model at different gas flows.
Design examples for different applications

**Example 1:** CHP, Primary exhaust gas Heat Exchanger

In-data (waste gas from natural gas, $\lambda=1.0$):

- Gas flow: 100 kg/h
- Gas Temp in: 420 °C
- Gas temp out: 105 °C
- Water flow: 3.0 m$^3$/h
- Water temp in: 49 °C
- Water temp out: 53.5 °C
- Total thermal effect: 13.2 kW

*AirecCalc design suggestion: Compact 25-C-20*

**Example 2:** Primary exhaust gas Heat Exchanger for 100 kW$_{el}$ CHP machine

In-data (waste gas from natural gas, $\lambda=1.0$):

- Gas flow: 461 kg/h
- Gas Temp in: 634 °C
- Gas temp out: 68 °C
- $\Delta P_{sideB}$: 3.2 mbar
- Water flow: 8.9 m$^3$/h
- Water temp in: 58.9 °C
- Water temp out: 67.5 °C
- $\Delta P_{sideA}$: 81 mbar
- Total thermal effect: 87 kW

*AirecCalc design suggestion: Compact 71-C-70*

**Example 3:** Secondary, condensing exhaust gas Heat Exchanger (for 50 kW$_{el}$ CHP)

In-data (waste gas from natural gas, $\lambda=1.0$):

- Gas flow: 190 kg/h
- Gas Temp in: 110 °C
- Gas temp out: 37 °C
- $\Delta P_{sideB}$: 0.3 kPa
Water flow: 2.0 m³/h
Water temp in: 30.0 °C
Water temp out: 37.0 °C
ΔP_{sideA}: 1.2 kPa
Total thermal effect: 16.3 kW

_AirecCalc design suggestion:_ **Compact 36-C-40**

**Example 4:** *Compressor intercooler (4 bar(a))*

In-data (Air at 3 bar(g)):

Air flow: 8 Nm³/h
Air Temp in: 150 °C
Air temp out: 35.3 °C
ΔP_{sideB}: 1.4 kPa

Water flow: 0.6 kg/s
Water temp in: 30.0 °C
Water temp out: 41.0 °C
ΔP_{sideA}: 5 kPa
Total thermal effect: 13 kW

_AirecCalc design suggestion:_ **Compact 37-C-40-D**

**Example 5:** *Compressor aftercooler (11 bar(a))*

In-data (Air at 10 bar(g)):

Air flow: 8 Nm³/h
Air Temp in: 200 °C
Air temp out: 40 °C
ΔP_{sideB}: 1.4 kPa

Water flow: 0.6 kg/s
Water temp in: 35.3 °C
Water temp out: 49.0 °C
ΔP_{sideA}: 3.5 kPa
Total thermal effect: 35 kW

_AirecCalc design suggestion:_ **Compact 37-C-60-D (NS2x30)**
### Example 6: Compressor aftercooler

In-data (Air at 6.9 bar(g)):

- **Air flow:** 2813 Nm$^3$/h
- **Air Temp in:** 200 °C
- **Air temp out:** 35 °C
- **$\Delta P_{sideB}$:** 2.4 kPa

- **Water flow:** 3.0 kg/s
- **Water temp in:** 30.0 °C
- **Water temp out:** 45.0 °C
- **$\Delta P_{sideA}$:** 25.5 kPa
- **Total thermal effect:** 160 kW

**AirecCalc design suggestion:** **Compact 73-C-140 (NS2x70)**

### Installation Considerations/System design and integration

Many possible problems can be avoided already in the design phase. A correctly mounted and connected heat exchanger should have a problem free operation if the operational environment is suitable for the heat exchanger.

#### 1. Compact

For closed heat exchangers as the Compact family are the mounting of the heat exchanger important in order to avoid mechanical, thermal, and corrosion damages. The heat exchanger has to be integrated into a system and by addressing this already in the design phase can possible problems be attacked before they become an issue. A Compact heat exchanger must never hang by its connections. External loads, like vibrations or pulsations, shall be avoided. Since Compact heat exchangers have an internal separation of the gas and the condensate, the placement of the condensate connection has to be considered in condensing applications. Airec can serve you with a step file of the selected Compact in order to facilitate the system integration.

#### a) Connection configuration

Airec offers four standard connection configurations, T, D, O, and G. For volume orders alternative configurations can be discussed. The standard configurations are shown in figure 13.
An important part of the system integration of the heat exchanger is how to connect the fluids. A standard Compact is not delivered as a “plug and play” heat exchanger. Connecting pipes and/or flanges for the gas flow have to be welded onto the heat exchanger first. If the operational condition is such that the heat exchanger is classified as a pressure vessel according to the PED regulation, the welding has to be performed by a certified welder.

In some cases might the piping dimensions in the system be different from the connection dimension of the suitable Compact version. In such case it is recommended to use conical transitions between the piping and the connection.

For volume orders the welding of pipes/flanges can be arranged by Airec.
c) **Stud Bolts**

A Compact heat exchanger cannot hang by its connections alone. Support is needed. The heat exchanger can be equipped with stud bolts at suitable locations on the top and bottom plate in order to give support points to fasten the unit.


d) **Vibrations**

Transfer of external vibrations into the heat exchangers is not allowed. The risk of mechanical failure is too high. Every possible transfer point should, if possible, be dampened. This can for example be done by using flexible piping.

2. **Cross 30**

a) **Casing**

Cross 30 needs an external casing to be functional. An example of a casing for two Cross 30 units in NS 2 configuration is shown in Figure 14. In this case the casing has been equipped with an inspection hatch at the top in order to be able to inspect the surfaces and if needed clean the surfaces with a high pressure wash. Further, a small condensate outlet has been incorporated in the bottom of the casing.

*Figure 14. Example of an external casing for Cross 30.*

Each casing tend to be unique, due to the customers’ requirements. There are some things to keep in mind when constructing a casing.
PED
If the operating pressure is below 0.5 bar(a) or above 1.5 bar(a) is the casing a pressure vessel according to the PED regulation. The rules for such a casing is described in PED, which should be consulted during the construction. The design of such a casing has to be certified by a certifying body.

Flow Direction
Cross 30 can be placed horizontal or vertical, see figure 15.

![Figure 15. Horizontal and vertical gas flows.](image)

In condensation applications it is important that the units are placed vertical with the gas flowing from the top down. By implementing this flow direction, the condensate will be forced to run downwards both by the gravity and by the gas flow. Further this placement do also secure minimal accumulation of condensate in the heat exchangers, which is beneficial from a corrosion resistance perspective. Stagnant condensate increases the risk of corrosion significantly.

Dismount ability
In applications where heavy fouling and/or precipitation are expected, e.g. heat recovery of diesel exhausts, can it be a good idea to implement the possibility to dismount the Cross 30 units. The heat exchangers can then be thoroughly cleaned before they are re-installed. One could also have spare/exchange units which could take the dirty units place, thereby shorten the downtime of the heat transfer.

b) Piping – ΔP
The piping dimensions for the gas flow and the coolant flow to and from the casing can be calculated in AirecCalc by using the subprogram “Pipe design”, see figure 16. The program becomes available when you made a calculation, click the on the name (blue) in the bottom right corner (see figure 7) and a separate window will pop-up.
Fill in a suitable standard DN size and check which flow velocity it will give for the current case. Suitable coolant flow (side A) is around 1 m/s (max. 3 m/s) and a flow velocity of 5 – 10 m/s is suitable for the gas (side B, max. 25 m/s). Adjust the DN size accordingly.
In all heat exchanger configurations where the coolant flow are connected through more than one heat exchanger are external connection pipes needed. This will give an additional pressure drop for the coolant circuit, side A. The additional pressure drop is included in the AirecCalc results. Please note that the additional pressure drop from the piping is calculated for flexible connecting pipes/hoses. Brazed heat exchangers tend to have heterogenic sizes/dimensions, Airec therefore prefer to use flexible piping when connecting the coolant circuit instead of tailor making the piping at each connection. It is planned to show the additional pressure drop for the piping, both smooth and flexible pipes, as separate results in the next version of AirecCalc.

c) Vibrations / Flow Pulsations
Airec has experience of heat exchanger failure due to transfer of external vibrations into the heat exchanger. In a casing without dismount ability can this be a costly failure. Therefore, all possible transfer points should be dampened, in cases where the operational environment is such that transfer of external vibrations can be anticipated.
2. **Limitations / Risks**

Airec heat exchangers should be considered as finely tuned instruments, there are limitations to the operational conditions they can endure. All of Airecs models are as standard copper brazed. Compact 25 and Cross 30 do also have nickel alloy MBF-51 as optional brazing material. The properties of the two available brazing materials differs. Copper forms strong and durable brazing joint, whereas nickel tend to form a bit weaker and somewhat more brittle brazing joints. Due to differences in the flow properties of the melt between the two brazing materials, the appearance of the final brazing joint differ. Copper forms large, kind of oversized joints, whereas nickel forms small, “undersized” joints. This also influence the mechanical properties of the final product.

It is also important to consider the compatibility of the materials in the heat exchanger with the fluids in the application. There are chemicals which are incompatible with metals or becomes it at certain concentrations or pH levels.

**Warning:** *Copper brazed heat exchanger must never be operated with ammonia, NH₃, or ammonia related substances. Copper corrodes rapidly in such environment.*

A. **Pressure**

Due to the difference in properties and type of joint formed by the two brazing materials, the pressure resistance differ quite much between heat exchangers which are brazed in the different materials.

All Airec heat exchangers have been tested and certified according to the European Directive for Pressure Equipment (PED 2014/68/EU). In table 7 are the current certified pressures listed.
Table 7. The current pressure certificates for the different Airec models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Size</th>
<th>Certified Pressure [bar(g)]</th>
<th>Certified Pressure [bar(g)]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Copper</td>
<td>Nickel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Side A</td>
<td>Side B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Static</td>
<td>Static</td>
</tr>
<tr>
<td>Compact25</td>
<td>Max 80</td>
<td>15 @ 25°C, 11 @ 190°C</td>
<td>8.2 @ 25°C, 6 @ 190°C</td>
</tr>
<tr>
<td>Compact26</td>
<td>Max 80</td>
<td>15 @ 25°C, 11 @ 190°C</td>
<td>8.2 @ 25°C, 6 @ 190°C</td>
</tr>
<tr>
<td>Compact36</td>
<td>Max 80</td>
<td>25 @ 25°C, 19 @ 190°C</td>
<td>Static</td>
</tr>
<tr>
<td>Compact37</td>
<td>Max 80</td>
<td>25 @ 25°C, 19 @ 190°C</td>
<td>17@ 25°C, 12.6 @ 190</td>
</tr>
<tr>
<td>Compact71</td>
<td>max 140</td>
<td>20 @ 25°C, 14.8@190°C</td>
<td>Static</td>
</tr>
<tr>
<td>Compact72</td>
<td>max 140</td>
<td>20 @ 25°C, 14.8@190°C</td>
<td>7 @ 25°C, 5.2@190°C</td>
</tr>
<tr>
<td>Cross30</td>
<td>max 140</td>
<td>11 @ 25°C, 8 @ 190°C</td>
<td>8 @ 25°C, 6 @ 190°C</td>
</tr>
</tbody>
</table>

Please note that boiling of the coolant can cause pressure shock which, besides having a deteriorating effect on the heat transfer, may cause severe damage on the heat exchanger. One should therefore always perform a risk analysis when the coolant has a boiling temperature below the maximum allowed plate temperature, 190 °C (374 °F). For such a coolant the boiling point can be transferred to a higher temperature by raising the coolant pressure.

**Warning:** The boiling risk warning in AirecCalc is calculated on the inlet pressure. In applications where the coolants boiling point at 1 bar, e.g. water boils at 99.606 °C @ 1 bar, is in close vicinity to the highest coolant temperature or when it is exceeded, should additional calculations be performed as a security measure. First of all; redo the calculation with the outlet pressure (inlet P – pressure drop) as new inlet pressure. If you get a warning of boiling risk, the original inlet pressure has to be raised with the pressure drop from the first calculation + an additional safety margin of at least 0.5 bar.
B. Temperature

Heat transfer means that you raise the temperature of one fluid by extracting the heat out of another fluid. For asymmetric heat exchangers like Airecs, this usually means that you transfer heat from a gaseous media (large volume flow) to a liquid media (low volume flow). There are a lot of ways to utilize Airecs heat exchangers, but there are a few temperature restrictions:

1. Plate Temperature

Airec heat exchangers are design to handle high gas temperatures. The temperature limit is governed by the plate temperature. The plate temperature must never exceed 190 °C (374 °F). Factors like coolant flow speed, initial coolant temperature, flow direction of the coolant, etc. affects the plate temperature. You will receive the following warning string when the plate temperature is exceeded; “Calculated plate temp above design value”. In such case, tweak around with the different factors until the plate temperature falls below the maximum allowed.

2. Freezing

The coolant should never be allowed to freeze in the heat exchanger. Beside the hassle of thawing the coolant channel before usage of the heat exchanger (the heat exchanger must never be operated without a coolant flow), the risk of severe damages to unit caused by the volume expansion of the freezing coolant (especially true for water) is too high.

3. Boiling

As mentioned above, the pressure shocks created by boiling coolant can critically damage the heat exchanger. Further, coolant boiling will have a large deteriorating effect on the heat transfer, so there is nothing to gain by letting the coolant boil.

C. Flows

Most flow dynamical and thermodynamical engineering problems are too complex to be deduced into exact equations. Instead semi-empirical equations based on dimensionless numbers are used. A dimensionless number can roughly be described as numbers without units which describes a fluids physical behaviour (for more exact description see “Buckingham π-theorem of dimensional analysis” or “dimensional analysis and similitude” in literature). There exist several name given numbers, the most important for heat exchanger calculations are, Reynolds number (indicate whatever the flow regime is laminar or turbulent), Re, Prandtl number (indicates if the heat transfer is faster or slower than the fluid velocity), Pr, and Nusselt number (used to calculate the heat transfer coefficient between a moving fluid and a solid body), Nu.

In AirecCalc are equations (taken from scientific literature) based on these numbers used for the calculations. Since these equations are based on experimental results are they only valid between certain flows. When a flow is lower or higher than this flow regime will the calculated result be error-prone and therefore not reliable, the magnitude of the discrepancy depends on how much higher/lower the flow is. In order to make the user aware of then the flow is outside the flow interval will warning strings like “High/Low flow velocity side A/B” be show in the information box.
D. Media Related
Not all fluids are compatible with the metals used in an Airec heat exchanger. Some, like ammonia, NH₃, are directly harmful towards one or more of the materials. In an ammonia environment, copper will corrode rapidly, in worst case within a few days. Beside the directly harmful chemicals, long term effects of trace elements in the operational fluids, e.g. salts, halogens, etc., should be considered since the can affect the lifetime and performance of the heat exchanger. When in doubt your welcome to ask Airec for guidance.

1. Corrosion
In gas-to-coolant heat transfer applications at temperatures below 700 °C can there only be two sources for corrosion, condensate from the gas or the coolant fluid. These are the only possible electrolytes in the application. For corrosion to take place is, the formation of a corrosion cell essential. It consists of four parts:

- **Anode** – the negative terminal of the cell. Electrons are released by oxidation at the anode, which is more reactive metal.
- **Cathode** – positive terminal of a cell. Reduction takes place at the cathode and electrons are consumed.
- **Electrolyte** – It is the electrically conductive solution (e.g. salt solution) that must be present for corrosion to occur.
- **Metallic path** – The two electrodes (anode & cathode) are connected externally by a metallic conductor.

All parts are essential, take away one, and the corrosion stop. This means that on heat exchanging plate, in a heat exchanger, exists two areas on the plate with sufficient difference in energy (due to e.g. impurity in the material), will, if they are simultaneously covered by a liquid, try to equalize the energy difference (second law of thermodynamics). At the high energy site, the anode, the material will start to dissolve, ions transfers from the surface material into the liquid. The released ions flows towards the low energy site, where they precipitate as corrosion products (e.g. rust). This is the overall mechanism of corrosion, there exist several variations or types of corrosion depending on environmental factors, influence of external forces or even combinations of both.

For heat exchangers in gas-to-coolant applications are there five types of corrosion to be considered:

1. **General corrosion** - A uniform thinning of a metal without any localized attack, i.e. corrosion at an even rate on the whole surface. This type of corrosion does not penetrate very deep inside the metal. Most familiar example the corrosion type is the rusting of steel in air.
2. **Galvanic corrosion** - When two metals with different potentials are joined, a galvanic cell is formed; a cell in which the chemical change is the source of energy, i.e. the driving force for the cell is the potential difference between the different materials. The cell is named after the Italian scientist Luigi Galvani, who described the phenomena in the late 18th century. This can also be described as when a metallic contact is made between a more noble metal and a less noble one, the corrosion rate will increase on the latter and
decrease on the former. The metal-to-metal contact has to take place in a corrosive electrolyte.

3. **Pitting corrosion** - A form of localized corrosion in which the attack is confined to a small fixed area of the metal surface leading to the formation of cavities or pits, and there the bulk of the surface remains unattacked. Pitting occurs due to a localized breakdown of the passive film (the protective layer of metal oxides which provides the corrosion resistance to most metals), hence are metals, which forms passive films, more susceptible to this form of corrosion. The presence of ions such as chloride, Cl\(^-\), bromide, Br\(^-\), and iodine, I\(^-\) in appreciable concentrations tend to cause pitting of steel. Thiosulfate, S\(_2\)O\(_3\)\(^2-\) (mainly), sulphate, SO\(_4\)\(^2-\), nitric oxide, NO\(_3\)\(^-\) and perchlorate, ClO\(_4\)\(^-\), also induce pitting on steel. The pitting process is often considered to consist of the following stages: 1) Local breakdown of passivity (pit nucleation), 2) early pit growth, 3) late (stable) pit growth, and (possibly) 4) repassivation. One or more of the pitting-causing ions, mentioned above, has to be present in sufficient concentrations. Pitting corrosion is promoted if the electrolyte has a stagnant flow (the pit inducing ions will have sufficient time to create a stable pit).

4. **Intergranular corrosion** - The metallic correspondent to a molecule is a crystal. In a crystal are the atoms arranged in that manner which minimizes the internal energy. Often are two or more atomic configurations (placement of the individual atoms in the crystal) energetically equivalent, especially in alloys, so more than one type of crystal are present in a macroscopic piece of metal. The different kinds of crystals tend to cluster together into larger grains, between these are there a small volume with impurities and odd crystals, named grain boundaries. Intergranular (intercrystalline) corrosion is the selective dissolution of grain boundaries. The grain boundary material, which is a limited area, acts as an anode, and the larger area of grains acts as cathodes. This results in the flow of energy from the small anode area to the large cathode area, which causes rapid attack penetrating deeply into the metal. *Airec heat exchangers should not be at risk for intergranular corrosion at normal operation conditions, since the steels used are low carbon steels and none of the brazing materials are attacked by this kind of corrosion.*

5. **Stress Corrosion Cracking, SCC** - SCC is defined as the delayed failure of alloys by cracking when exposed to certain environments in the presence of static tensile stress. It is a phenomenon associated with a combination of static tensile stress, environment and in some systems, a metallurgical condition which leads to component failure due to the initiation and propagation of a hairline crack. The tensile stresses may originate from external load, centrifugal forces or temperature changes, or they may be internal stresses induced by cold working, welding or heat treatment. The cracks are mainly formed in planes normal to the tensile stresses, and propagate intergranularly or transgranularly, more or less branched. If they are not detected in time, they will cause fast, unstable fracture. The environment causing stress corrosion is specific for each metal. *The stress level in the material after brazing have been investigated by Airec and found to be low (in our products), therefore is SCC usually not a problem to be considered for Airec heat exchangers.*
2. Fouling / Scaling
Small particles or dissolved chemicals might precipitate from the fluids when the temperature alters. Precipitates can either scratch the surfaces or form a deposit on the surface, both have a deteriorating effect on the heat transfer. The flow dynamics becomes altered above a scratched surface and a deposit becomes isolating towards the heat transfer surface. In process engineering these two phenomena (there exist other) are called Fouling.

Water, especially hard water, naturally contains a certain amount of dissolved salts. When the temperature of the water rises the solubility of some of the salts will diminish. At ca. 60 – 65 °C salts of calcium, Ca, barium, Ba, and magnesium, Mg, tend to precipitate out from water. These salts forms a rather hard scale on top of the surface it precipitate onto. This kind of fouling is usually referred to as Scaling.

If you suspect that fouling could be a factor in the application you are calculating this should be addressed by using the fouling factor box in the calculation window.

3. Recommended Water Quality
The definition of acceptable water quality is different all over the world. For the operation with water as coolant, Airec recommend that you apply the following requirements:
- The water has to be colorless, clear and free from undissolved matter.
- Fresh water supply is not allowed.
- A continuous oxygen/air entry (dissolving in the water in side A) is not allowed.
- The hardness of the water should not exceed 8 °dH (equivalent to ~ 1.5 moles/m³ according to the United States Geological Survey classification).
- The electric conductivity should not exceed 500 µS/cm.
- The chloride content should not exceed 30 mg/l (30 ppm).
- The sum of the chlorides, nitrates and sulfates should not exceed 50 mg/l (50 ppm).
- The pH-value should be found between 8 and 9.

In addition, EN 14868 should be taken into consideration.

4. Particle size
Particles can scratch the heat exchanging surfaces or even clog the coolant channels and thereby lessen the efficiency of the heat transfer. Generally, no particle should be larger than 2/3 of the coolant channel (side A) height, Airec recommend that no particle should be larger than 1 mm and that a sieve/strainer with suitable mesh size is installed before the water inlet.

E. Installation Related
To secure a long life time of the heat exchanger should potential risk be addressed already in the design phase. Since the heat exchangers will be incorporated into a system are there some risks which are necessary to inform the system designers about when they incorporate Airecs products into their systems. Airec can provide step files of the heat exchangers if it facilitate the incorporation.
1. **Vibrations**

Airec do not allow vibrations to be transferred into the heat exchanger. The heat exchanger plates will sooner or later crack, much in the same manner as a metal wire breaks when bended back and forth several repeated times, if the plates are subjected to continuous vibrations. The time until failure depend on the amplitude and frequency of the vibration. Airec have seen in claim cases that the vibration caused crack tend to appear in areas in vicinity to the different connections (the most common transfer point of vibrations). To avoid this are flexible pining solutions recommended. Airec do also, if possible, recommend that the attachment points of the heat exchanger will be equipped with some form of dampening.

2. **Flow Pulsations**

All process flows tend to have small variations from the nominal in flow speed and pressure. If these variations occurs with smooth transitions will the effect on a heat exchanger be minor. It is when the variation occurs in a pulsating manner problems start. The effect of this kind of pulsating flow is similar to the effect of vibrations, mechanical damages can be caused on the heat exchanger. Pulsating flows are typical seen when the heat exchanger is installed directly after a blower or just before a pump. In such cases are some kind of muffler recommended, advantageously installed between the heat exchanger and the pressure device.

3. **Mounting Related Damages**

Airec have seen cases there defects have been caused on our products by faulty installation. There have been cases there the connections have forced to fit with too short piping, which have instigated unnecessary mechanical tensions in the heat exchanger material. These tensions have then in combination with other loads (thermal, vibrational, corrosive, etc.) eventually lead to a failure of the heat exchanger. This is another reason why flexible connections are recommended (it is easier and cheaper to replace a faulty pipe than a heat exchanger). It is important that the mounting of the heat exchanger does not build-in tensions or stresses into the heat exchanger.

F. **Operation Related**

Even if the heat exchanger is mounted as it is supposed to be and the operational environment is not harmful, can damages on the heat exchanger occur due to heavy use or faulty operation.

1. **Thermal Fatigue**

A temperature change in a material induces thermal expansion (or contraction). If surrounding material or external constraints hinder this expansion thermal stresses arises in the material. Cyclic loads of kind, i.e. alternating heating and cooling, are known to cause cracks and eventual failure of the material, a phenomenon called thermal fatigue. The effects of thermal fatigue are similar to those of mechanical fatigue. 

The load do not have to be cyclic in order to cause material failure, a material under constant stress will eventually crack if it is not allowed to relax.

Typical sites in a heat exchanger are areas on the heat exchanging plate which do not come in sufficient contact with the coolant. This can be caused by maldistribution of the coolant between
the channels in the heat exchanger or by laminar coolant flow, which both are a result of too low coolant flow rate.

2. **Mechanical Fatigue**

Material ages when it is subjected to stresses and strains, even if they are very small. By time a material will answer to these loads, becoming less elastic and more plastic, therefore it will start to crack and in the end it will fail. This process is called mechanical fatigue. The progress of the phenomena is stressed when the loads are cyclic. In order to protect the heat exchanger towards this phenomena, transfer of vibrations to the heat exchanger and pressure pulsations in the fluid flows should be as minimal as possible.

3. **Boiling Risk**

If a coolant boils during operation, even locally, it will have a deteriorating effect on the heat transfer. The pressure shock associated with the volume expansion a boiling coolant can causes, will in most cases create severe damages. A coolant can therefore never be allowed to boil. **Warning:** The boiling risk warning in AirecCalc is calculated on the inlet pressure. In applications where the coolants boiling point at 1 bar, e.g. water boils at 99.606 °C @ 1 bar, is in close vicinity to the highest coolant temperature or when it is exceeded, should additional calculations be performed as a security measure. First of all; redo the calculation with the outlet pressure (inlet P – pressure drop) as new inlet pressure. If you get a warning of boiling risk, the original inlet pressure has to be raised with the pressure drop from the first calculation + an additional safety margin of at least 0.5 bar.
3. Appendices

A. Appendix A – Airec Product data sheets

B. Appendix B – Equation used for two phase calculations

To create a two phase media Airec need to know the following thermal [Kelvin] behaviour of the properties at atmospheric or rather 1 bar pressure, the unit for each are given inside brackets. The constants given in the formulas are the ones needed to create media for the software. If the constants cannot be provided, tabulated values of the thermal behaviour of the property at 1 bar pressure must be provided, to be used for re-calculation by Airec. If possible please also provide the temperature span the formulas are valid for:

**Enthalpy of vaporisation:**

\[ \Delta H_{\text{vap}} \left[ \frac{kJ}{mol} \right] = A \left(1 - \frac{T}{T_C}\right)^n, \text{const. } A, n \]

**Liquid density:**

\[ \text{density} \left[ \frac{g}{ml} \right] = AB^{-\left(1 - \frac{T}{T_C}\right)^n}, \text{const. } A, B, n \]

**Liquid viscosity:**

\[ \log_{10} n_{\text{liq}} \left[ \text{centipoise} \right] = A + B/T + CT + DT^2, \text{const. } A, B, C, D \]

**Liquid thermal conductivity:**

\[ \log_{10} k_{\text{liq}} \left[ \frac{W}{(m \cdot K)} \right] = A + B \left[1 - \frac{T}{C}\right]^{2/7}, \text{const. } A, B, C \]

**Liquid specific heat:**

\[ C_p \left[ \frac{J}{(mol \cdot K)} \right] = A + BT + CT^2 + DT^3, \text{const. } A, B, C, D \]

**Vapour pressure:**

\[ \log_{10} P \left[ \text{mm Hg} \right] = A + \frac{B}{T} + C \log_{10} T + DT + ET^2, \text{const. } A, B, C, D, E \]

**Vapour viscosity:**

\[ n_{\text{gas}} \left[ \text{micropoise} \right] = A + B \cdot T + C \cdot T^2, \text{const. } A, B, C \]

**Vapour conductivity:**

\[ k_{\text{gas}} \left[ \frac{W}{(m \cdot K)} \right] = A + B \cdot T + C \cdot T^2, \text{const. } A, B, C \]

**Vapour specific heat:**
$C_p \left[ \frac{J}{(mol \cdot K)} \right] = A + B \cdot T + C \cdot T^2 + D \cdot T^3 + E \cdot T^4$, const. $A, B, C, D, E$

C. Appendix C – Examples of module assemblies

Figure 17. Examples of module assemblies
Figure 18. Examples of module assemblies

FD1-NS4-PA1-PB1

FD1-NS1-PA1-PB4

FD1-NS2-PA1-PB2

FD2-NS2-PA1-PB1

Figure 19. Examples of module assemblies
Figure 20. Examples of module assemblies

Figure 21. Examples of module assemblies
D. Appendix D – Example Calculations

Side A (liquid) | Side B (gas)
---|---
Flow rate | 2,00 kg/s | 2000,00 m³/h
Operating pressure | 6,00 bar | 1,00 bar
Temperature In | 40 °C | 350 °C
Temperature Out | 49,40 °C | 131,47 °C
Pressure drop | 136,19 mbar | 2,74 mbar
Heat transferred | 78,55 kW |
Temperature efficiency | 70,5 % |

Comments:
- Heat transferred from the hot gas to the liquid is 78,55 kW.
- Temperature efficiency (side B) is 70,5%.
- If the hot gas is cooled down to 40 °C, entering temperature of the liquid, the temperature efficiency (side B) is 100 %.

Side A (liquid) | Side B (gas)
---|---
Flow rate | 2,00 kg/s | 2000,00 m³/h
Operating pressure | 6,00 bar | 1,00 bar
Temperature In | 40 °C | 350 °C
Temperature Out | 49,94 °C | 131,47 °C
Pressure drop | 38,02 mbar | 0,72 mbar
Heat transferred | 83,06 kW |
Temperature efficiency | 73,4 % |

Comments:
- Flow division 2 (FD2) means the liquid (side A) and the gas (side B) are split into two parallel flows passing through the two equal heat exchanger modules.
- Flow division 3 (DF3) means the liquid (side A) and the gas (side B) are split into three parallel flows passing through three equal heat exchanger modules, etc.
- Pressure drop is lower on both gas and liquid as the velocities are reduced in proportion to number of modules.
- Main advantage of increasing the Flow division is reduction in pressure drops.
AIREC AB

Airec Technical Handbook - Heat exchanger types, selection and applications

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**Side A (liquid)**  **Side B (gas)**

**Flow rate**
2,00 kg/s  2000,00 m³/h

**Operating pressure**
6,00 bar  1,00 bar

**Temperature In**
40 °C  350 °C

**Temperature Out**
53,96 °C  68,85 °C

**Pressure drop**
271,58 mbar  4,69 mbar

**Heat transferred**
116,67 kW

**Temperature efficiency**
90,7 %

**Comments:**
- Number of steps 2 (NS2) means the liquid (side A) and gas (side B) flow will pass through two heat exchanger modules in series.
- Number of steps 3 (NS3) means the liquid (side A) and gas (side B) flow will pass through three heat exchanger modules in series, etc.
- Pressure drop increase on both liquid and gas as it runs in series through all heat exchangers.
- Heat transferred and temperature efficiency increase.
- Main advantage of increasing the Number of steps is to increase heat transferred and temperature efficiency to a maximum.

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**Side A (liquid)**  **Side B (gas)**

**Flow rate**
2,00 kg/s  2000,00 m³/h

**Operating pressure**
6,00 bar  1,00 bar

**Temperature In**
40 °C  350 °C

**Temperature Out**
50,66 °C  119,48 °C

**Pressure drop**
271,88 mbar  0,71 mbar

**Heat transferred**
89,07 kW

**Temperature efficiency**
74,4 %

**Comments:**
- Side B parallel 2 (PB2) means the gas (side B) flow will pass in parallel through two heat exchanger modules. The liquid (side A) will pass in serial through the two heat exchanger modules.
- Side B parallel 3 (PB3) means the gas (side B) flow will pass in parallel through three heat exchanger modules. The liquid (side A) will pass in serial through the three heat exchanger modules, etc.
- Pressure drop decrease on gas (side B), but increase on liquid (side A).
- Heat transferred and temperature efficiency increase is slightly better than a FD2 assembly.
- Main advantage of increasing the Side B parallel is to decrease pressure drop on side B (gas).

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