Czech University of Life Sciences Prague

Faculty of Engineering

# Technical economical evaluation of the copper use in the construction of the brazed plate heat exchangers in the conditions of the Czech Republic

Diploma Thesis

Thesis Supervisor: doc. Ing. David Herák, Ph.D.

Thesis author: Bc. Michal Janča

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**CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE**

Department of Mechanical Engineering

Faculty of Engineering

# DIPLOMA THESIS ASSIGNMENT

Michal Janča

Technology and Environmental Engineering

Thesis title

**Technical economical evaluation of the copper use in the construction of the brazed plate heat exchangers in the conditions of the Czech Republic**

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**Objectives of thesis**

The aim of thesis is to describe technical economical evaluation of the copper use in the construction of the brazed plate heat exchangers in the conditions of the Czech Republic.

**Methodology**

Review part of this thesis should include a description of the currently used construction of the brazed plate heat exchangers in the conditions of the Czech Republic. The experimental part of this thesis will contain technical economical evaluation of the copper use in the construction of the brazed plate heat exchangers in the conditions of the Czech Republic. Data for this analysis should be collected from the companies, which are focused on production of the heat exchangers.

**The proposed extent of the thesis**

40 – 50 p

**Keywords**

mechanics, termodynamics, mechanics of materials, engineering

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**Recommended information sources**


Hsieh, J.S.: Principles Of Thermodynamics. Mcgraw-Hill, New York, 1975

Ježek, J., Váradiová, B., Adamec, J.: Mechanika Tekutin. ČVUT, Praha, 2000

Munson, B.R., Young, D.F., Okiishi, T.H.: Fundamentals Of Fluid Mechanics. John Willey, New York, 2002, 840 S

Neuberger, P., Adamovský, D., Adamovský, R.: Termomechanika. Technická Fakulta ČZU, Praha, 2007

White, F.M.: Fluid Mechanics. Mc Graw Hill, New York, 2003, 866 s


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**The Diploma Thesis Supervisor**

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**doc. Ing. Pavel Neuberger, Ph.D.**

Head of department

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**prof. Ing. Vladimír Jurča, CSc.**

Dean

Prague on 27. 03. 2015

**Statement**

I declare that I have work out diploma thesis: „Technical economical evaluation of the copper use in the construction of the brazed plate heat exchangers in the conditions of the Czech Republic“, just myself with leading by doc. Ing. David Herák, Ph.D. and used only literatures listed in bibliography. The electric version is the same as the printed version and I agree that the Thesis may be made available for consultation with agreement of Department of Mechanical Engineering.

In Prague

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Michal Janča

**Acknowledgements**

**Doc. Ing. David Herák, Ph.D.**, Thesis Supervisor for expert consultations, substantive comments and assistance in processing of Thesis.

I would like to thank the **Alfa Laval s.r.o.,** which I used for analysing the technical data and expert consultations. Special thank is for **Ing. Michal Ekrt** and **Ing. Eduard Janča, Ph.D. MBA.**

Last but not least, I would like to thank my parents, **Marie Jančová and Eduard Janča,** for allowing me to realize my own potential. All the support they have provided me over the years was the greatest gift anyone has ever given me.

In Prague

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Michal Janča

**Technicko-ekonomické zhodnocení použití mědi v konstrukcích pájených deskových výměníků v podmínkách ČR**

**Abstrakt:** Příjemné vnitřní prostředí v obytných domech, průmyslových a veřejných budovách je dnes absolutní standard. Uživatelé očekávají příjemnou teplotu okolního vzduchu i vody. Je proto bezpodmínečně nutné účinné řízení teploty. Z ekonomického a ekologického pohledu musí být ideální teplota zajištěna s využitím co možná nejmenšího množství energie a se souladem s životním prostředím. Tato práce představuje deskové výměníky tepla, které jsou klíčovými komponenty celé řady systémů centrálního zásobování teplem, vytápění a přípravy teplé vody. V rámci práce byly ve spolupráci se zainteresovanými firmami sestaveny skupiny, ve kterých se posuzovaly deskové výměníky tepla s výměníky trubkovými na základě zvolených kritérií. Další část práce poukazuje na technický stav dvou mědí pájených deskových výměníků tepla z praxe v jedné teplárně po pěti letech provozu. Získané výsledky a poznatky posloužily jako doporučení pro teplárny, který typ výměníku je vhodno k použití na základě zvolených kritérií v podmínkách ČR.

**Klíčová slova:** mechanika, termodynamika, mechanika materiálů, strojírenství, výměník tepla

**Technical economical evaluation of the copper use in the construction of the brazed plate heat exchangers in the conditions of the Czech Republic**

**Summary:** Comfortable indoors place in houses, industrial and public buildings is absolute standard at present. Users expect a pleasant temperature of air and water. Have effective control of the temperature is necessary. The ideal temperature has to be ensured by using the possible smallest amount of energy and environmentally friendly for economic and environmental point of view. This thesis presents brazed plate exchangers which are main components a lots of systems of district heating and tap water. During the preparation of the thesis, groups were established in cooperation with interested companies, which were used to assess plate exchangers in comparison with shell-and-tube exchangers based on selected criteria. Another part of the thesis shows the technical condition of two copper brazed plate exchangers after five years of operation in a heat plant. The results and information obtained were used to conclude which type of exchanger can be recommended to heat plants for use based on selected criteria under the conditions present in the Czech Republic.

**Key words:** mechanics, thermodynamics, mechanics of materials, engineering, heat exchanger

# Content

# 1 Introduction

Heated tap water is part of everyday life and is one of basic needs. This is the reason why tap water installation must be reliable, economical and above all provide hygienically clean water. District heating is environmentally friendly and reliable method of delivering comfort heating. It is great opportunity to have flexible and energy efficient use waste heat from industry, waste incineration, industrial processes and sewage or in heating plans. Solutions that are complete and easy to install for supply district heating and hot tap water suitable is centralized heat supply.

The centralized heat supply is a reliable and environmentally favourable method of supply of district heating and hot tap water, which also brings about the possibility of using waste heat from industrial operations. For efficient preparation district heating/hot tap water, heat exchangers play an important role. Brazed and fusion-bonded heat exchangers are used for applications requiring inexpensive solution in compact size. These two types of exchangers are mainly used in compact heat exchanging stations for hot tap water preparation or for district heating. Hot tap water flows from the heat source in the heat station to a heat exchanger, which isolates the sources from the centralized heat supply pipe system. Then the heat is distributed to various end users, where heat exchanging stations ensure the transfer of heat to individual buildings. These stations usually consist of one heat exchanger for district heating and another for hot tap water preparation.

# 2 Objectives of work

The aim of thesis is to describe technical economical evaluation of the copper use in the construction of the brazed plate heat exchangers in the conditions of the Czech Republic.

The experimental part of this thesis will contain technical economical evaluation of the copper use in the construction of the brazed plate heat exchangers in the conditions of the Czech Republic. Data for this analysis should be collected from the companies, which are focused on production of the heat exchangers. For these purposes, a collaboration was started with the Alfa Laval Company, which is among the leading manufacturers of heat exchangers and disposes of extensive experience in production of compact heat transfer stations.

After consultations with Alfa Laval, the following methodology procedure was selected to achieve this objective, which corresponds with the assignment of the thesis:

- Assessment of copper brazed plate heat exchangers in the conditions of the Czech Republic.
- Evaluation of a specific case in one heating plant with assessment of suitability of implementation of copper brazed heat exchangers for hot tap water production and district heating.
- The discussion of the thesis consists of the recommendation of the most suitable model of certain selected heat exchangers with respect to their economical parameters.

# 3 Literature Overview

Heat exchangers are devices that provide the transfer of thermal energy between two or more fluids at different temperatures. Heat exchangers are used in a wide variety of applications, such as power production, process, chemical and food industries, electronics, environmental engineering, waste heat recovery, manufacturing, industry, air-conditioning, refrigeration, space applications, ets (Shah, 1981).

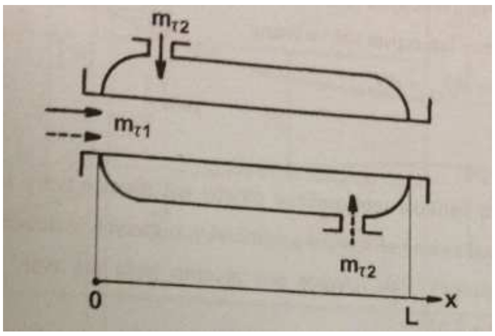
## 3.1 Types and classification of heat exchangers

Based on the method of heat transfer between substances, heat exchangers can be divided as follows:

- **Recovery heat exchangers** - heat exchangers, where the heat is exchanged by passage through a heat transfer area dividing the substances. Exchangers of this type are used in almost all cooling equipment and heat pumps with very rare exceptions (Dvořák, 1992).
- **Mixer heat exchangers** (in some industries called contact exchangers) are based on direct contact between the substances and the heat transfer is usually connected with a transfer of mass. Such heat exchangers include e.g. mixing steam/water injectors, cooling towers of heat power plants etc.
- **Regeneration heat exchangers** - the medium is warmed up by the warmer (cooled) substance and cooled down by the cooler (warmed) substance alternatively. These exchangers include e.g. combustion air heaters in high-output boilers.

### 3.1.1 Recuperative heat exchangers

**Figure 1 – Diagram of recovery heat exchanger**



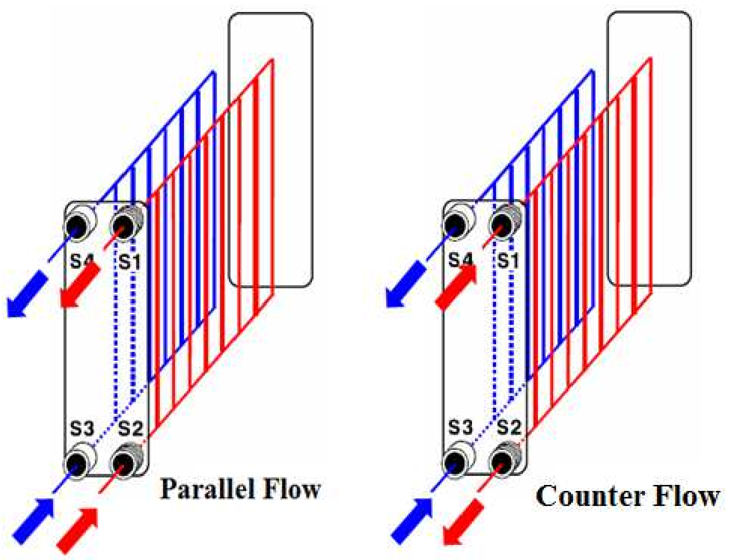

**Source – Sedláček, 2007**

The simplest example of a recuperative heat exchanger is a tube with a small diameter inserted in a tube of larger diameter - see the figure 1.

Recuperative heat exchangers are very diverse in terms of function as well as design; they can be classified as follows:

- **By the number of substances participating in the heat exchange**
  - Double-media exchanger
  - Triple-media exchanger
- **By the flow direction of medium through exchanger** - there are three basic configurations of flow of both liquids; based on the flow direction, exchangers can be divided into the following groups:
  - Parallel Flow exchanger, where both liquids flow along the heat transfer area in the same direction (shown by solid arrows in Figure 2).
  - Counter Flow exchanger, where the liquids flow along the heat transfer area in opposite directions (shown by dashed arrows in Figure 2).

**Figure 2 – Example of a parallel flow and counter flow configuration of a plate exchanger**

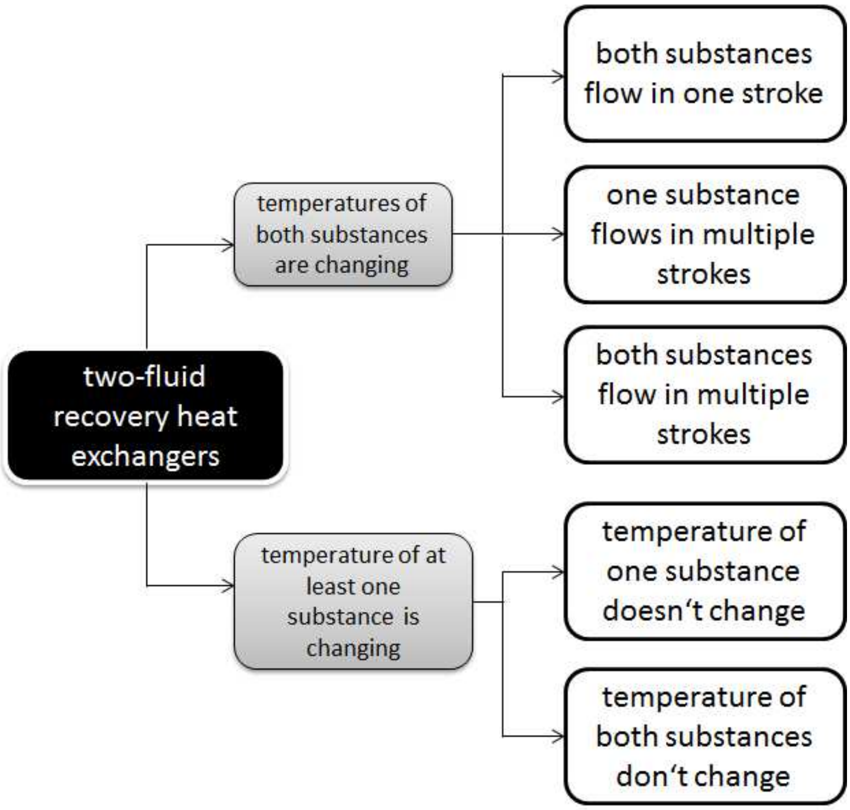



**Source – Alfa Laval, s.r.o.**

  - Cross flow heat exchanger, where the speed vectors for both liquids are perpendicular.

- **By configuration of flow of both media** - see the figure bellow

**Figure 3 – Classification of recovery heat exchangers by configuration of flow of media**




**Source – Dvořák, 1992**

- **By design layout** - below is list the main types of recovery heat exchangers used at present in cooling systems and in various secondary heat utilization systems.
  - Double tube exchangers
    - Bundle double tube exchanger
    - Spiral double tube exchanger
  - Shell-and-tube exchangers
    - Shell-and-tube exchanger with baffles
    - Horizontal shell-and-tube exchanger
    - Bundle shell-and-tube exchanger
    - Vertical shell-and-tube exchanger
  - Bundle exchangers
    - Bundle exchanger in open tank
    - Cross blow bundle exchanger
    - Sprinkling condenser
    - Evaporating exchanger

- Coil-wound exchangers
    - Small coil-wound exchangers
    - Large coil-wound exchangers
- Plate exchangers
    - Plate fin exchangers
    - Plate exchangers with fused plates
    - Demountable plate exchangers
- Heat transfer tubes

### 3.1.2 Mixer exchangers

Mixer exchangers can used as chillers for heat transfer and, possibly, concurrent transfer of mass (humidification, desiccation) between liquid and gas or vapour, assumed there are no unwanted physical or chemical reactions between both media.

**The main characteristics include:**

- Possibility of achieving a small difference between the output temperatures of both substances.
- Usually lower weight of the exchanger or its metal parts compared to a recovery exchanger. The dimensions and flow resistance are quite similar to recovery exchangers.
- Possibility to concurrently capture solid particles (dust from air), dissolution (washing) of gaseous or liquid impurities, absorption of condensed moist or condensation of vapours of a substance identical to the cooling fluid.

### 3.1.3 Regenerative exchangers

Regenerative exchangers are heat exchangers where both liquids flow along the same wall surface, which accepts heat and cools down the warmer liquid during the heating period and releases heat and warms up the cooler liquid during the cooling period.

## 3.2 Design calculations for recovery exchangers

Calculation of flow resistance is essential for dimensioning machine for circulating substance in exchanger. Especially when trying to intense heat transfer by increasing turbulence is important to realize that increase the flow rate, causes an increase transfer coefficient (Dvořák, 1986).

The thermal calculations of recovery heat exchangers are based on the thermal balance equation and heat conduction equation.

### 3.2.1 Thermal balance equation

Assumed the exchanger is perfectly thermally insulated from the environment, i.e. the heat loss is equal to zero, and then the entire heat flux extracted from the warmer fluid is accepted by the cooler fluid. The thermal balance equation for the entire heat transfer area has the following form:

$$|Q_{t1}| = Q_{t2} = Q_t \qquad [W] \qquad (3.1)$$

The equation must also be valid for each element of the heat transfer area, i.e. in its differential form:

$$|dQ_{t1}| = dQ_{t2} = dQ_t \qquad [W] \qquad (3.2)$$

To allow heat transfer, the liquid marked as / is the warmer liquid marked as 2. Heat is extracted from liquid 1; therefore the heat flux $Q_{t1}$ is negative whereas the heat flux $Q_{t2}$ is positive. That is why all the positive forms above use the absolute values. It is clear that the balance equation can be reformed as follows:

$$-dQ_{t1} = dQ_{t2} = dQ_t \qquad [W] \qquad (3.3)$$

### 3.2.2 Heat conduction equation

As already mentioned, in practice are exchangers where the dividing heat transfer area is planar (plate exchangers). In this case, the heat conduction equation has the following form:

$$dQ_t = q_t dS = k_r (t_1 - t_2)_x B dx \qquad [W] \qquad (3.4)$$

B = width of heat transfer area [m]

$(t_1 - t_2)_x$ = local temperature difference between both liquids at the position of elemental area dS [K] (3.5)

$k_r$ = heat transfer coefficient through the planar heat transfer area:

$$k_r = \frac{1}{\frac{1}{\alpha_1} + \frac{s}{\lambda} + \frac{1}{\alpha_2}}$$

[W*m$^{-2}$*K$^{-1}$] (3.6)

$\alpha_1$ = The heat transfer coefficient between the warm medium and the heat transfer surface [W*m$^{-2}$*K$^{-1}$]

$\alpha_2$ = The heat transfer coefficient between the heat transfer surface and the cold medium [W*m$^{-2}$*K$^{-1}$]

s = thickness of single-layer planar wall [mm]

λ = the thermal conductivity of the material separating the media [W*m$^{-1}$*K$^{-1}$]

During integration of the heat conduction equation, must be taken into account the variability of local temperature gradient along the heat transfer area.

Another common type of the heat transfer area is represented by cylindrical surfaces in tube exchangers. The heat conduction equation can be compiled using the following relation:

$$dQ_t = q_r * dx = k_v(t_1 - t_2)_x dx$$

[W] (3.7)

$(t_1 - t_2)_x$ = local temperature difference between both liquids at the position of given elemental tube segment dx [K] (3.8)

$k_v$ = heat transfer coefficient through the cylindrical heat transfer area

$$k_v = \frac{2\pi}{\frac{1}{\alpha_1 * r_1} + \frac{1}{\lambda} ln\frac{r_2}{r_1} + \frac{1}{\alpha_2 * r_2}}$$

[W*m$^{-2}$*K$^{-1}$] (3.9)

### 3.2.3 Heat transfer coefficient

Zemansky and Dittman (1997) state that "heat is internal energy in transit." Logan (1999) recognize that work, too, is energy in transit. This terminology distinguishes work and heat from the amount of energy contained by a body or system. It is then simply the amount of energy that has flowed into or out of a system or control volume during the course of a process.

What is it that happens to the system when energy is added? The molecules of a gas or liquid translate with greater velocity and thus contain greater kinetic energy. In solids the atoms bound in their lattice structure oscillate with greater energy increasing the stored energy within the solid material. Energy enters the system as work when an external force move through a distance, whereas energy flows into the system as heat when there is a temperature difference between the surroundings and the system. On the other hand, if there is no temperature difference between the system and its surroundings, no heat will flow in or out of the system, and the system is said to be in thermal equilibrium with its surroundings. The movement of energy as a result of temperature differences is called heat transfer (Logan 1999).

The heat transfer coefficient is equal to the amount of heat transferred from the warmer substance to the cooler substance through unit area of heat transfer area (i.e. to heat flux density) with a unit temperature difference between both substances. The total overall heat transfer coefficient k is defined as:

$$\frac{1}{k} = \frac{1}{\alpha_1} + \frac{1}{\alpha_2} + \frac{\delta}{\lambda} + R_f = \frac{1}{k_c} + R_f \qquad [-] \qquad (3.10)$$

$$M = \frac{k_c - k}{k} \qquad [\%] \qquad (3.11)$$

| | | | |
|---|---|---|---|
| $\delta$ | = | the thickness of the heat transfer surface | [m] |
| $R_f$ | = | the fouling factor | [$m^2$*K*$W^{-1}$] |
| $k_c$ | = | clean heat transfer coefficient ($R_f = 0$) | [W*$m^{-2}$*$K^{-1}$] |
| k | = | design heat transfer coefficient | [W*$m^{-2}$*$K^{-1}$] |
| M | = | design margin | [%] |

Combination of these two formulas gives:

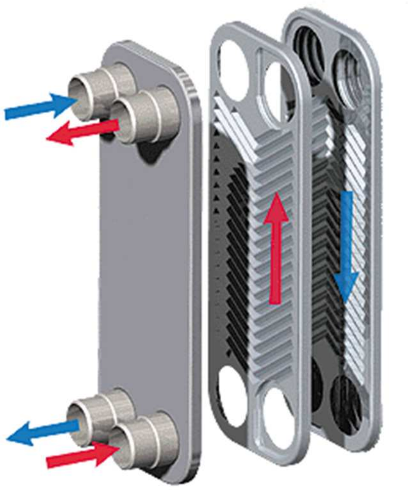
$$M = k_c * R_f \qquad [\%] \qquad (3.12)$$

I.e. the higher $k_c$ value, the lower $R_f$ value to achieve the same design margin.

## 3.3 Plate heat exchangers

Channels are formed between the plates and the corner ports are arranged so that the two media flow through alternate channels. The heat is transferred through the plates and complete counter-current flow is (as a rule) arranged for highest possible efficiency.

**Figure 4 – Plate heat exchanger**



**Source – McMillan, 2006**

Plate heat exchangers are built of plates forming flow channels. The fluid streams are separated by flat plates which are smooth or between which lie corrugated fins. Plate heat exchangers are used for transferring heat for any combination of gas, liquid, and two-phase streams (Kakaç, Pramuanjaroenkij, 2012).

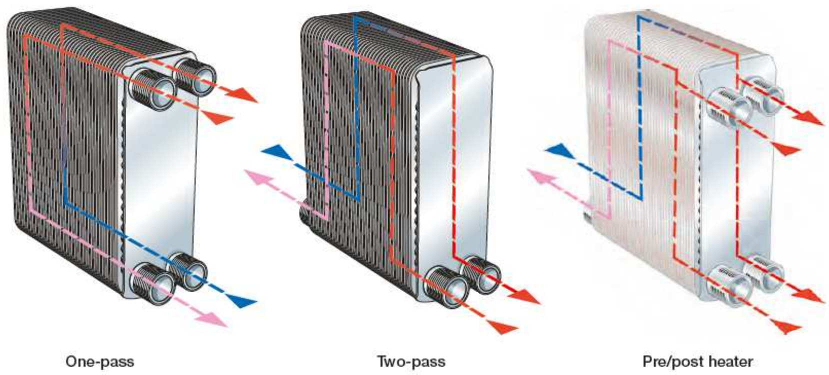
### 3.3.1 Design options

To achieve the most efficient heat transfer in heating and cooling applications, brazed heat exchangers are configured in either concurrent or countercurrent layout.

- One-pass - All connections are located on one side of the heat exchanger, which considerably simplifies its installation.
- Two-pass

- Pre/post heater - Cooling with two coolant types

**Figure 5 – Examples of various layouts of brazed plate heat exchangers**




**Source – Alfa Laval, s.r.o.**

### 3.3.2 Types of plates

The efficiency of heat transfer in the exchanger and the possibility of accurate regulation of the heating/cooling process depend, to certain extent, on the plate thickness. Each plate is molded in a hydraulic press under the pressure of up to 40 000 tonnes by a single stroke to the common thickness of 0.4 mm. All the plates are perfectly identical, which minimizes the risk of deformation and leakages, which can occur in large bundles (which can consist of several hundreds of plates).

The exchanger plates are molded in so-called fishbone profile. When two plates with opposite fishbone profiles are placed together, they create a spiral flow route with very high turbulences, which are prerequisite for a high heat transfer coefficient and efficient self-purification of the exchanger. There are also other plate profile patterns, which allow using the exchangers for other processes, e.g. in case of strongly contaminated media.

The distribution area is molded in so-called chocolate pattern. This innovative type of corrugation is literally a revolutionary feature for the heat transfer technology. This profile brings a number of advantages. The most important ones include optimized flow distribution across the entire heat transfer area in parallel layout and, above all, elimination of dead zones in the corners, which usually result in clogging and corrosion.

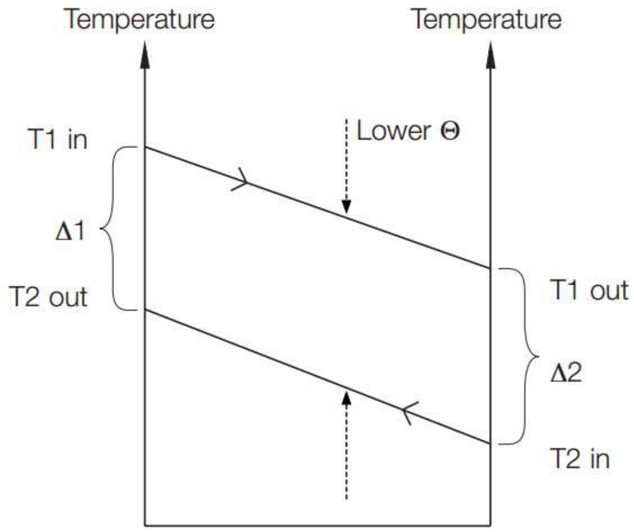
The profiled surface of the plates forms flow channels, supports turbulences and creates support points. The “chocolate” profile of the distribution area ensures homogeneous distribution of the liquid across the plate surface, while the “fishbone” profile ensures maximum turbulences on the heat transfer area. All these features together ensure highly efficient heat transfer, eliminating dead zones that could cause clogging and corrosion.

### 3.3.3 Types of channels

**At present, two plate profiles are commonly offered:**

- L plate profile – large temperature differences give low Theta value (figure 6).

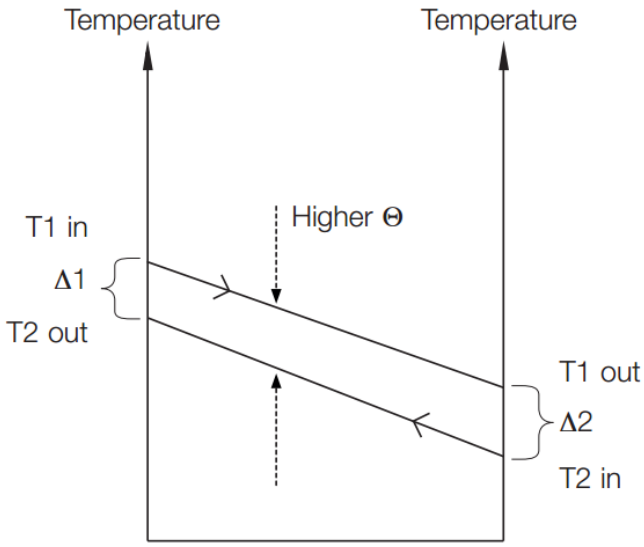
**Figure 6 – Low Theta value**




**Source – Alfa Laval, s.r.o.**

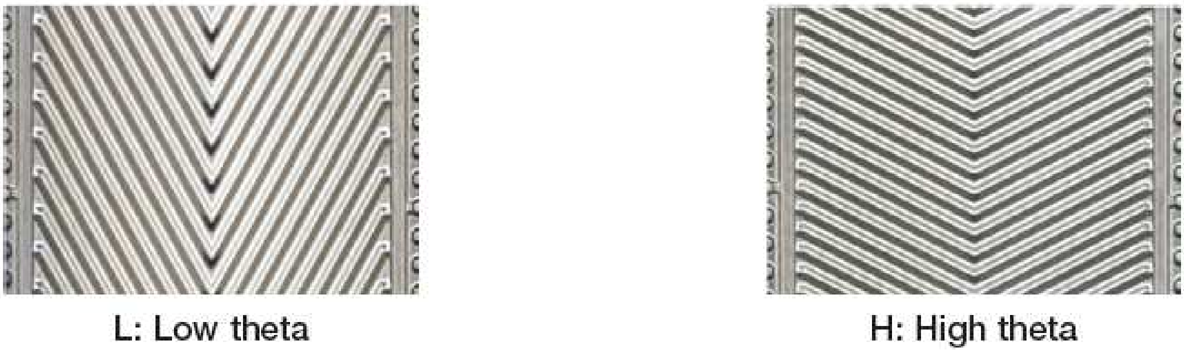
- H plate profile – small temperature differences give high Theta value (figure 7).

**Figure 7 – High Theta value**




**Source – Alfa Laval, s.r.o.**

**Figure 8 – Plate profiles**




**Source – Alfa Laval, s.r.o.**

For some duties, cooling applications for example, the temperature program is very tight with close approaches on the different temperatures. This gives what it is referred to as high theta duties and requires high theta units. High theta duties are duties that have Θ > 1 and are characterized by:

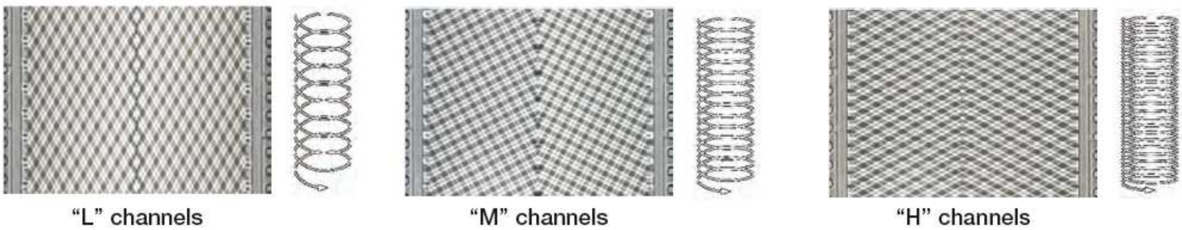
- long plate, longer time for the fluid to be cooled
- low pressing depth that fives less fluid per plate to be cooled

Plate heat exchangers are superior compared to shell-and-tube heat exchangers when it comes to theta values. Shell-and-tube heat exchangers can go up to a maximum value of theta ~ 1 while plate heat exchangers goes up to theta values of 10 and more. For a shell-and-tube to climb over theta value of 1 or more, several shell-and-tube needs to be put in series.

**Combining these two profiles, three types of channels can be created:**

- *"L" channels* - low turbulence and pressure loss
- *"M" channels* - medium turbulence and pressure loss
- *"H" channels* - high turbulence and pressure loss

**Figure 9 – Types of channels**




**Source – Alfa Laval, s.r.o.**

**Advantages and benefits of those channels:**

- Efficient heat transfer
- High turbulence
- Variable thermal length
- Low pressure loss
- High reverse heat utilization
- High self-purification capability
- Small heat transfer area
- Low costs of pumping

### 3.3.4 Calculation of the Heat load, Thermal length (Theta value) and LMTD

$$P = m * c_p * \Delta T \qquad [kW] \qquad (3.13)$$

$$\Theta = \frac{\Delta T}{LMTD} = \frac{k * A}{m * c_p} \qquad [-] \qquad (3.14)$$

The LMTD value may be calculated using the following formula, where $\Delta T_1 = T_1 - T_4$ and $\Delta T_2 = T_2 - T_3$

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{ln \frac{\Delta T_1}{\Delta T_2}} \qquad [K] \qquad (3.15)$$

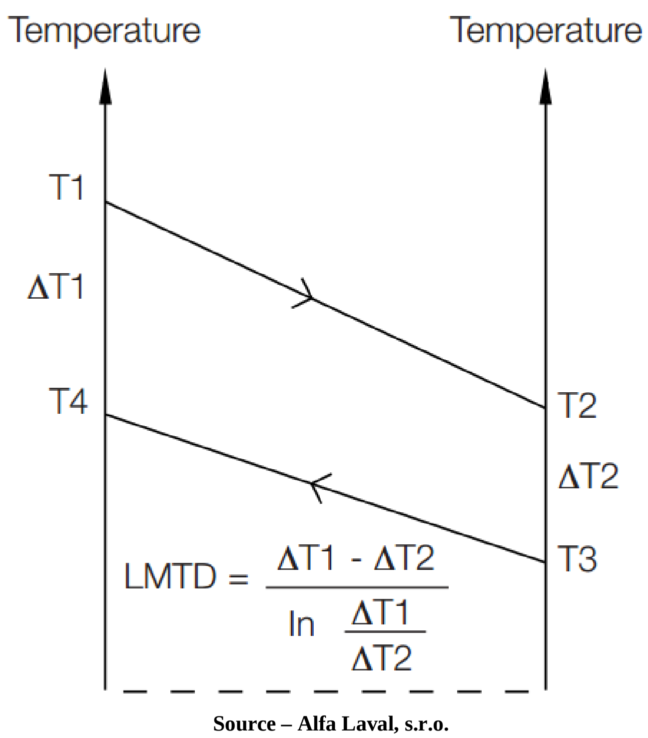
| | | | |
|---|---|---|---|
| P | = | heat load | [kW] |
| $\Delta T$ | = | difference between inlet and outlet temperatures on one side | [K] |
| $\Theta$ | = | Theta value | |
| A | = | heat transfer area | [$m^2$] |
| m | = | mass flow rate | [$kg*s^{-1}$] |
| $c_p$ | = | specific heat | [$kJ*kg^{-1}*K$] |
| $T_1$ | = | inlet temperature - hot side | [K] |
| $T_2$ | = | outlet temperature - hot side | [K] |
| $T_3$ | = | inlet temperature - cool side | [K] |

| | | | |
|---|---|---|---|
| $T_3$ | = | outlet temperature - cool side | [K] |
| LMTD | = | logarithmic mean temperature difference | [K] |

The amount of mass flowing through a cross section per unit time is called the mass flow rate. It takes different amounts of energy to raise the temperature of identical masses of different substances by one degree. Therefore, it is desirable to have a property that will enable to compare the energy storage capabilities of various substances. This property is the specific heat. The specific heat is defined as the energy required to raise the temperature of a unit mass of a substance by one degree. In general, this energy depends on how the process is executed. In thermodynamics are two kinds of specific heats: specific heat at constant volume $c_v$ and specific heat at constant pressure $c_p$. Expression for specific heat at constant pressure $c_p$ can be obtained by considering a constant-pressure expansion or compression process. (Çengel and Boles, 2008). Thermal length calculation uses specific heat at constant pressure $c_p$.

Logarithmic mean temperature difference is the effective driving force in the heat exchanger. See picture 10. The larger the temperature difference between the medias is, the smaller the heat exchanger will be. Temperature program means the inlet and outlet temperatures of both media in the heat exchanger.

**Figure 10 – Temperature program**



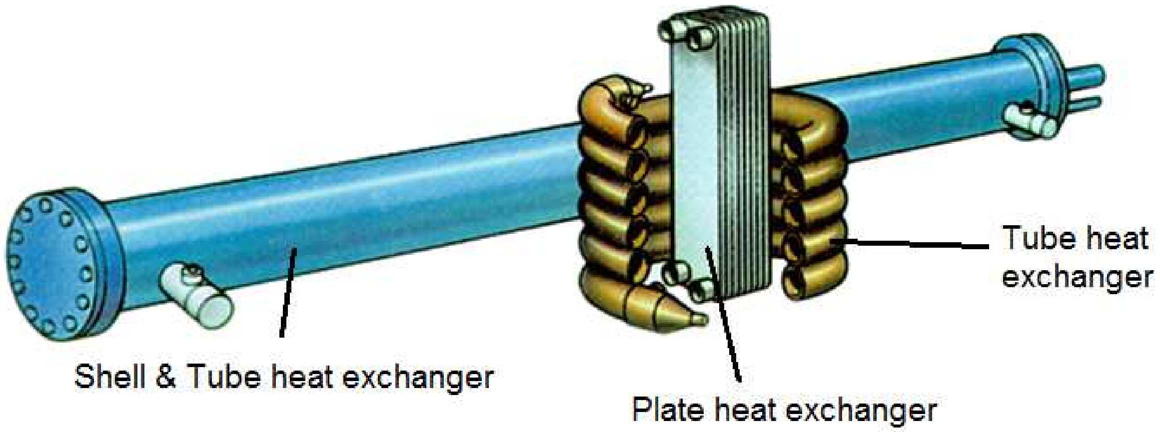

**Source – Alfa Laval, s.r.o.**

### 3.3.5 Advantages

In most cases the plate type is the most efficient heat exchanger. Generally it offers the best solution to thermal problems, giving the widest pressure and temperature limits within the constraint of current equipment. The most notable advantages of a plate heat exchanger are:

- Size and weight – takes up much less space and has lower weight than another constructions (Figure 11).

**Figure 11 – Size of heat exchangers**




**Source – Alfa Laval, s.r.o.**

- High heat transfer rate – they utilize the thinnest material for the heat transfer surface that in turn gives optimum heat transfer, since the heat only has to penetrate thin material (McMillan, 2006). Plate Heat Exchangers have a high heat transfer rate compared to other types of heat exchangers due to their large surface area.

- Compatibility – plate Heat Exchangers have a number of applications in the pharmaceutical, petrochemical, chemical, power, industrial dairy, and food & beverage industry.

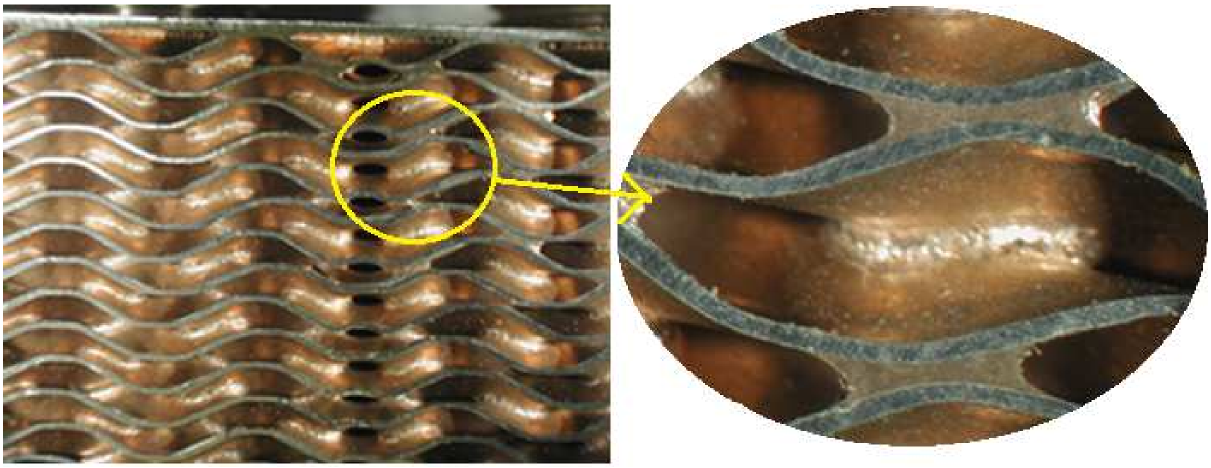
- Efficiency – High turbulence in the medium that in turn gives a higher convection, which results in efficient heat transfer between the media. The consequence of this higher heat transfer coefficient per unit area is not only a smaller surface area requirement but also a more efficient process (McMillan, 2006). The high turbulence also gives a self-cleaning effect. Therefore, when compared to the traditional shell-and-tube heat exchanger, the fouling of the heat transfer surfaces is considerably reduced. This means that the plate heat exchanger can remain in service far longer between cleaning intervals.

- High quality – The brazed plate heat exchangers are individually tested. They are designed to withstand many factors, especially temperature and pressure variations in load conditions.

### 3.3.6 Copper brazed

Brazed plate heat exchanger consists of thin profiled moulded plates made of a high grade stainless steel, which are joined by vacuum brazing using copper in a furnace. The plates are arranged in such a manner that there are channels between them for the primary and secondary media, to which the heat carrier liquid is distributed through inlet ports. The heat passes through the walls of individual plates, allowing heat exchange between the media.

**Figure 12 – Copper brazed parts**



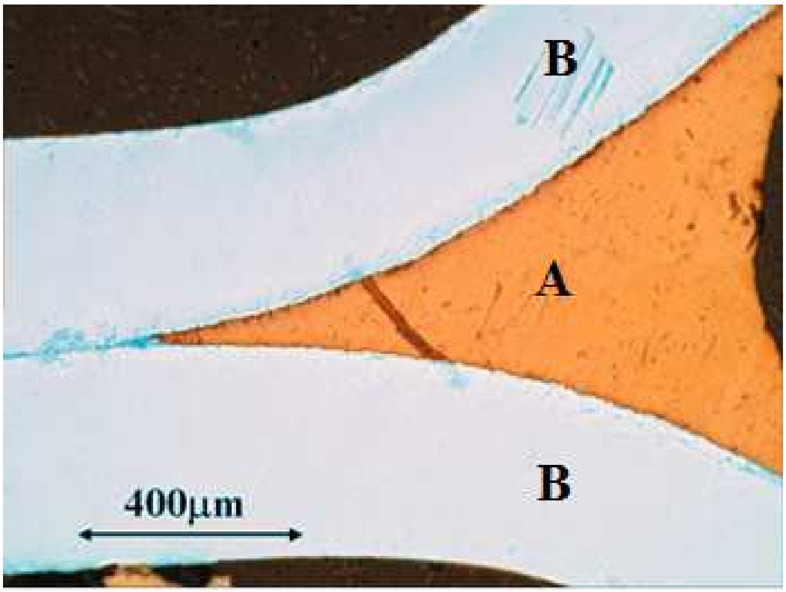
**Source – Alfa Laval, s.r.o.**

At the contact points between the corrugated plates, a thin layer of copper is melted at high temperature. Since copper has good capillary action, i.e., good capability to wet the plate and fill crevices, the filler gathers where the plates have contact, sealing and strengthening the plate pack. The method of joining the stainless steel plates by brazing eliminates the need for sealing and thick frame plates. The brazing material seals and connects the plates using contact points. Brazed heat exchangers are joined at all the contact points, which ensures the optimum efficiency of heat transfer and high pressure resistance.

Although copper brazing causes adhesion between the copper and the stainless steel, there is no surface reaction between the materials. The combination of stainless steel and copper offers good ductility. Under pressure, substantial material deformation can occur before splitting occurs. The build-up of stress in the material causes it to change direction, thus relieving the mechanical load.

While copper brazing results in a high quality plate heat exchanger, the brazing process must be carefully controlled, otherwise copper may penetrate the stainless steel. This results in liquid metal embrittlement, a known metallurgical phenomenon which reduces the strength of the heat exchanger.

**Figure 13 – Contact points between the corrugated plates and thin layer of copper**




**Source – Alfa Laval, s.r.o.**

A – Filler material

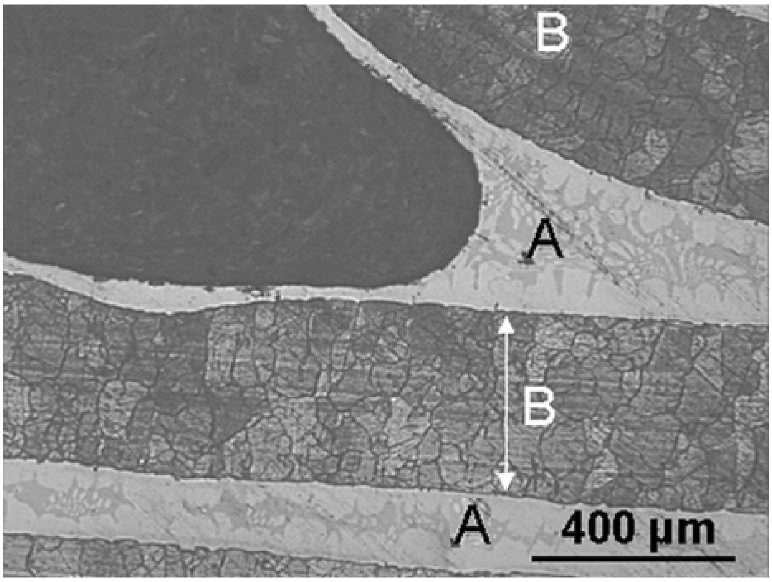
B – Plate material

The plates are designed so as to achieve maximum life service possible. The fact the almost all material is used for heat transfer allows brazed exchangers to have very compact dimensions, low weight and small retaining volume. The advantages of plate exchangers include compact size, easy adjustment of output by connecting more plates and perfect countercurrent in adjacent plates.

A two-material process, copper brazing is an efficient, cost effective method of manufacturing plate heat exchangers. On the other hand they are limited in their temperature performance and applications due to the presence of copper.

### 3.3.7 Nickel brazed

**Figure 14 – Contact points between the corrugated plates and thin layer of nickel**




**Source – Alfa Laval, s.r.o.**

A – Filler material

B – Plate material

Nickel foil is placed between the corrugated stainless steel plates and the plate pack is brazed in a furnace.

Since the melting point of stainless steel is about 1 400°C and that of nickel around 1 500°C, boron and silicone are added to the nickel to lower its melting point to approximately 1 100°C. However, adding boron creates problems. While stainless steel normally contains 17% chrome, during brazing, the boron penetrates the stainless steel and forms chrome borides.

These lower the chrome content of the stainless steel around the joins to below 14%, lowering the corrosion resistance of the plates and reducing ductility. Stainless steel can normally be extended by 50% before breakage occurs. Nickel brazing decreases ductility to below 5% and it will break immediately when deformed under pressure.

The chrome borides also make the nickel filler hard and brittle, further reducing the strength of the heat exchanger. Since nickel has poor capillary action, it is crucial that the plates are in contact with each other during brazing, and rejects in production are common.

The nickel brazed plate heat exchanger is an alternative for applications where copper is not appropriate, such as de-ionized water or ammonia. Nickel brazed plate heat exchangers are limited in their mechanical performance.

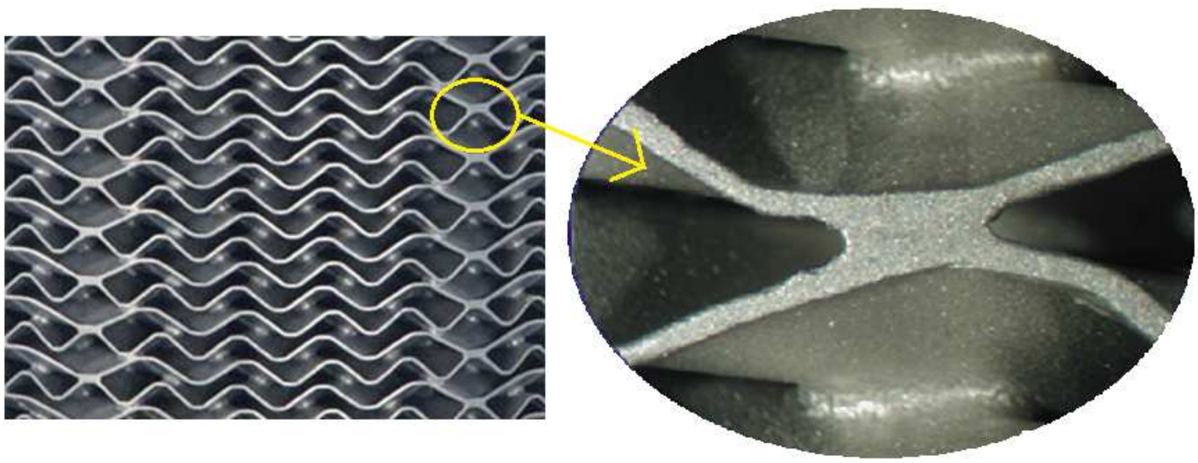
### 3.3.8 Fusion-bonded plate heat exchanger (AlfaFusion technology)

Fusion-bonded plate heat exchanger can handle high temperatures and has good resistance to pressure fatigue compared to a conventional brazed plate heat exchanger.

Fusion-bonded plate heat exchanger consists of a number of corrugated stainless steel plates, a frame plate, a pressure plate and connections – all in stainless steel.

The result is the fusion-bonded plate heat exchanger, a whole new class offering extremely high mechanical strength. It is also hygienic, corrosion-resistant and fully recyclable. Unbeatable reliability The AlfaFusion technology creates a plate heat exchanger with possibilities to go much higher in temperature than conventional brazed units. Its 100% stainless-steel design allows Fusion-bonded plate heat exchanger to withstand temperatures of up to 550°C.

**Figure 15 – Fusion-bonded parts**

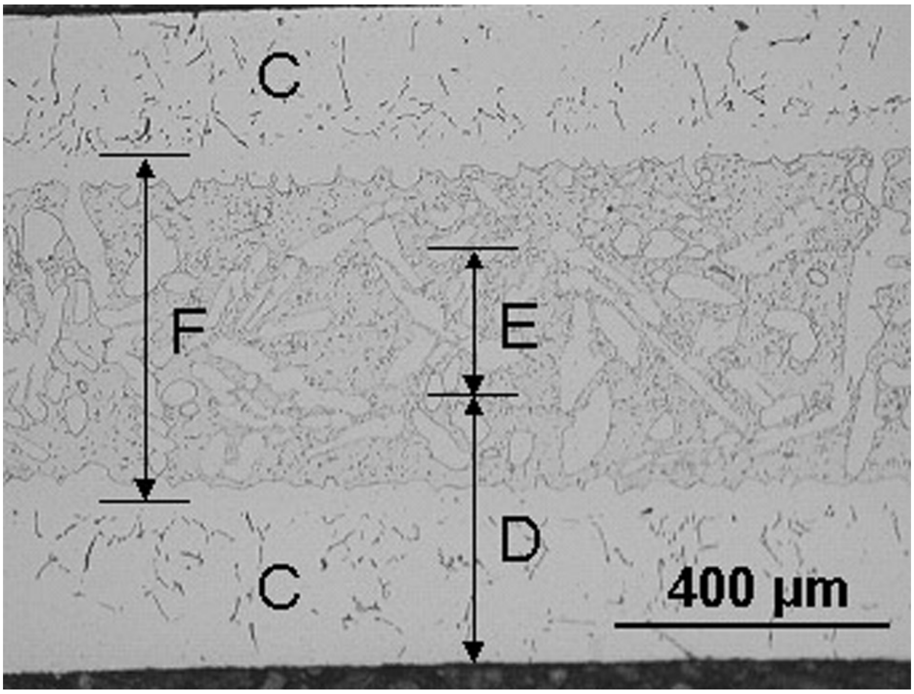


**Source – Alfa Laval, s.r.o.**

**AlfaFusion**

A new joining method to put together stainless steel component. The interaction between the stainless steel plate material and the filler metal during heat treatment (TLP bonding) results in a homogenous unit where the chemical and mechanical properties of the joints is similar the properties of the plate material.

**Figure 16 – AlfaFusion method**




**Source – Alfa Laval, s.r.o.**

D – Original plate material

E – Original filler material

F – Homogenisation

C – Plate

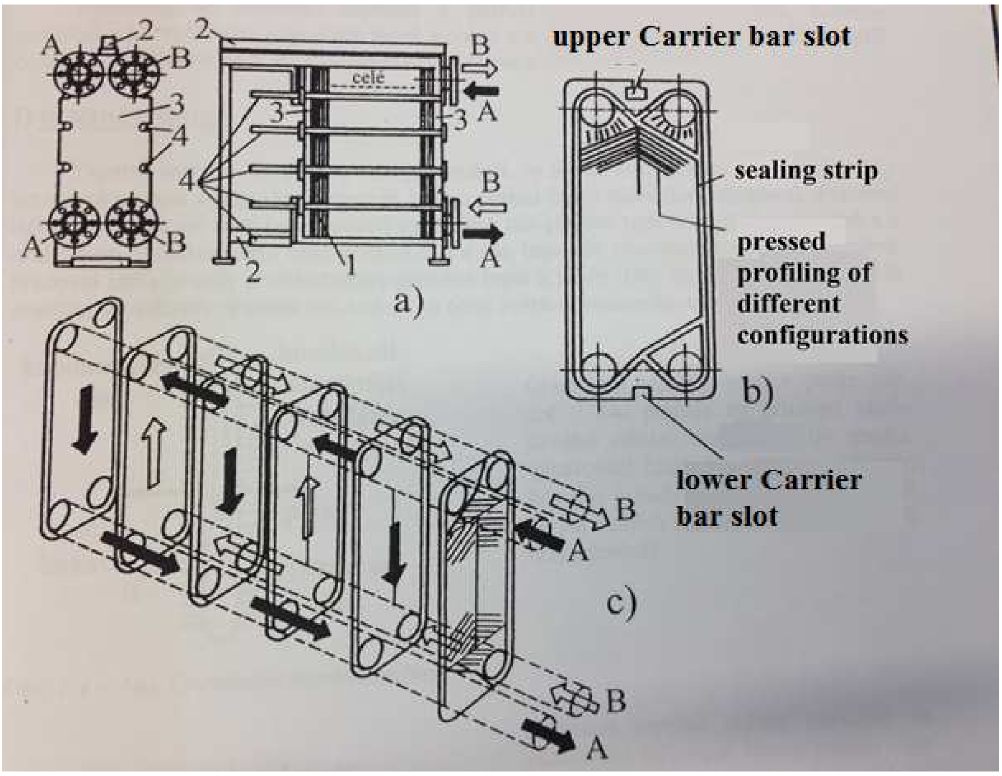
Success lies in precise temperature control to achieve the correct melting depth and to avoid melting through the plates. Due to the properties of the fusion zone, AlfaFusion gives a homogenous plate heat exchanger with a high level of corrosion resistance and higher, or almost the same resistance to mechanical and thermal fatigue as other technologies.

#### 3.3.9 Gasketed plate heat exchangers

The plates consist of any operationally suitable and sufficiently ductile materials allowing molding (steels including stainless steels, aluminium, titanium, alloys) and are amply profiled to:

- Create suitable flow channels with very small hydraulic diameters, allowing high heat transfer and limited creation of deposits (approx. 20% compared to shell-and-tube exchangers), while preventing accumulation of non-condensing gases.
- Reinforce the design to allow use of material of thickness lower than 1 mm.

**Figure 17 – Exchanger made of molded plates**




**Source – Sedláček, 2007**

The overall layout of the exchanger shown in Figure 17a consists of individual plates (1) of shape as per Figure 17b suspended on carrier bars (2) and, together with face plates (3), constricted by screw bolts (4). The flow of substances A (solid arrows) and B (hollow arrows) between individual plates is shown in Figure 17c.

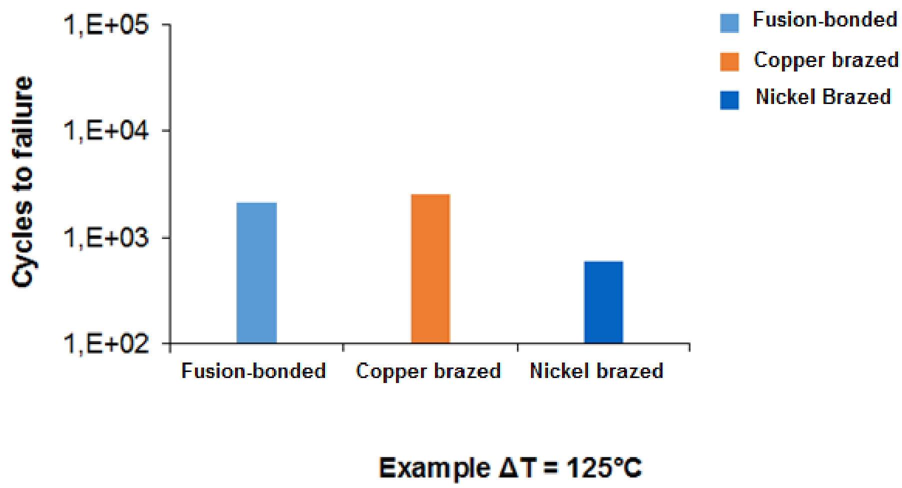
Gasketed plate heat exchangers are limited in their temperature performance and chemical compatibility. Requires maintenance.

3.3.10 Mechanical performance

The number e is called limit of $(1+1/n)^n$ where n approaches infinity and it is irrational number (Sikorová, 1998). Using this number is expressed as cycles of failure on the charts.

Picture 18 is shown temperature variations. That is how many cycles the plate heat exchanger can withstand a temperature change of 125 degrees. On the vertical part of chart are cycles to failure and on the horizontal part are types of plate heat exchangers. Fusion-bonded and copper brazed are almost equal in lifetime in terms of thermal fatigue. Note that nickel brazed are far away from copper brazed and fusion-bonded; that comes from the really lousy stainless steel material in the nickel brazed. The stainless steel material is totally destroyed by the boron who is used to lower the melting point for the nickel foil.

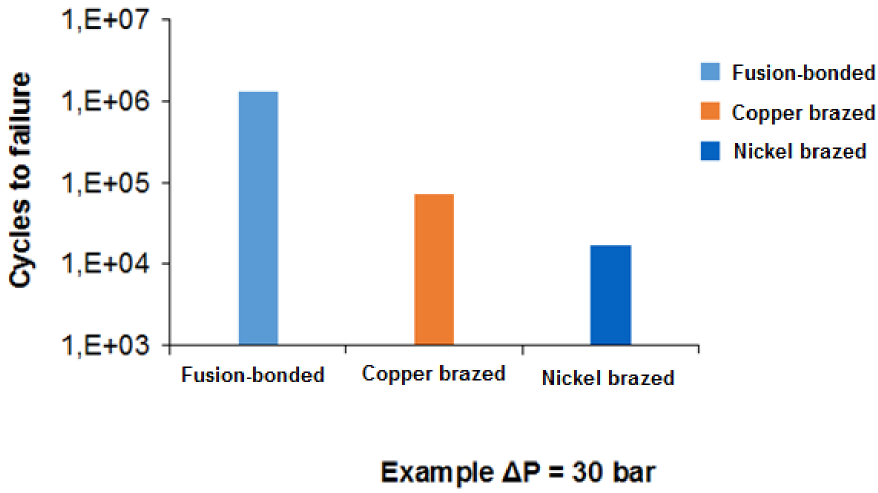
**Figure 18 – Temperature variations**




**Source – Alfa Laval, s.r.o.**

Picture 19 is shown pressure variations. That is how many cycles the plate heat exchanger can withstand a pressure change of 30 bars. Fusion-bonded is outstanding in pressure fatigue. Because in pressure fatigue the join at the contact points takes the load from the pressure. The strongest joins are in fusion-bonded, they are much stronger than in copper brazed and nickel brazed. Again nickel brazed performs much less than fusion-bonded and copper brazed.

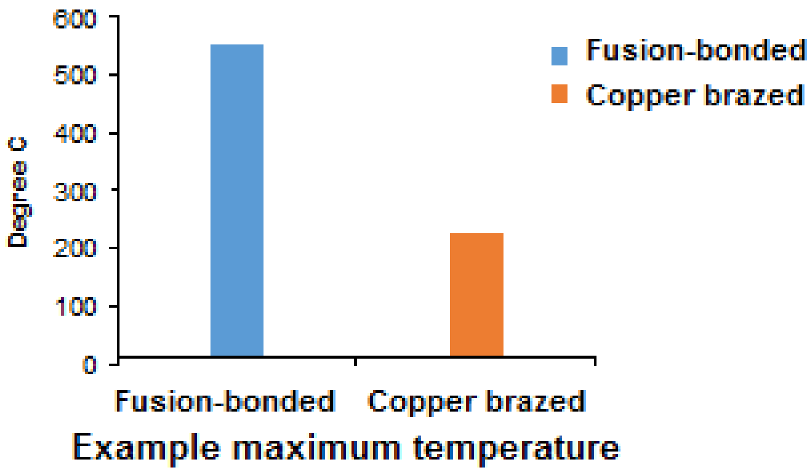
**Figure 19 – Pressure variations**




**Source – Alfa Laval, s.r.o.**

On picture 20 is maximum temperature for fusion-bonded and copper brazed heat exchangers. Advantage for fusion-bonded is maximum temperature is 550°C. For copper brazed is just 225°C.

**Figure 20 – Maximum temperature**




**Source – Alfa Laval, s.r.o.**

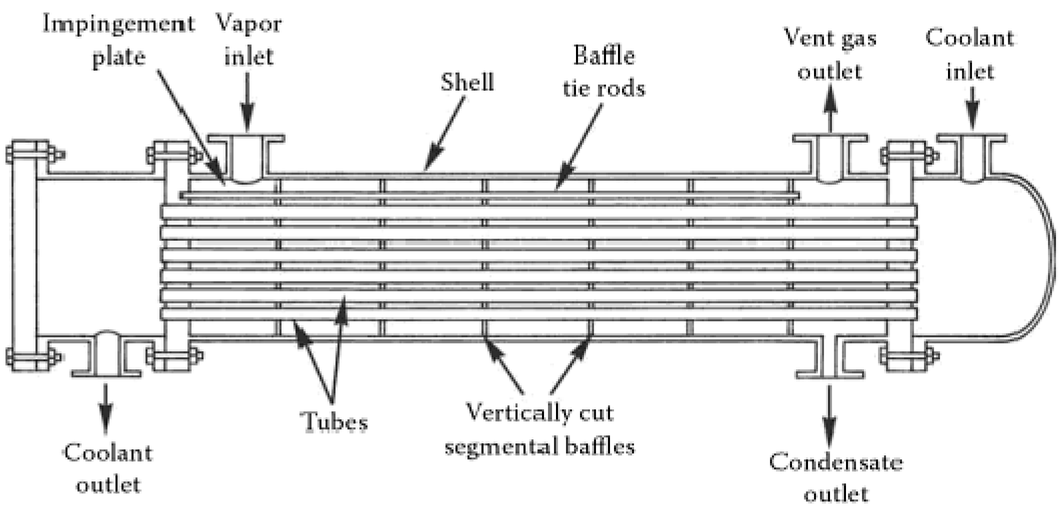
### 3.4 Shell-and-tube heat exchangers

The shell-and-tube heat exchanger is named for its two major components – round tubes mounted inside a cylindrical shell. The shell cylinder can be fabricated from rolled plate or from piping (up to 24 inch diameters). The tubes are thin-walled tubing produced specifically for use in heat exchangers. Other components include: the channels (heads), tubesheets, baffles, tie rods & spacers, pass partition plates and expansion joint (when required).

Shell and tube heat exchangers are significant components in many industries, particularly in energy conversion systems. The heat transfer requirements and the total cost of shell and tube exchangers are important factors in their incorporation in designs in industrial applications. An optimum design, in terms of both economics and efficiency, can be obtained through appropriate selection of design parameters (Sadeghzadeha, Ehyaeib and Rosenc, 2015).

Shell-and-tube heat exchangers are built of round tubes mounted in large cylindrical shells with the tube axis parallel to that of the shell. They are widely used as oil coolers, power condensers, preheaters in power plants, steam generators in nuclear power plants, in process applications, and in chemical industry. The simplest form of a horizontal shell-and-tube type condenser with various components is shown in figure 21. One fluid stream flows through the tube while the other flows on the shell side, across or along the tubes. In a baffled shell-and-tube heat exchanger, the shell-side stream flows across pairs of baffles and then flows parallel to the tubes as it flows from one baffle compartment to the next. There are wide differences between shell-and-tube heat exchangers depending on the application (Kakaç and Pramuanjaroenkij, 2012).

**Figure 21 – Horizontal shell-and-tube**



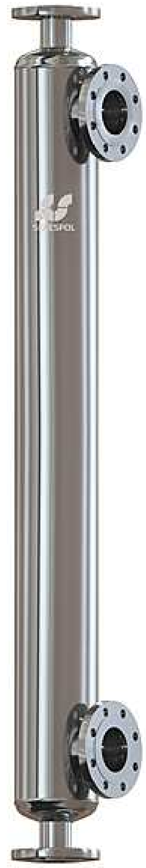

**Source – TEMA. 1988**

The shell-and-tube have merits that are often crucial, such as very low-pressure loss on the primary side and the ability to operate at high temperatures and pressures. Easy inspection and cleaning is possible during maintenance due to its construction. For high temperature applications up to 600°C a special design is needed whereby each tube is individually sealed with heat resistant seals. This allows for high temperature differences between any two media in the shell-and-tube and small overall sizing resulting in compact design.

Cross-counter flow must be used in multi-pass and pure counter flow is always employed in single-pass applications. All water headers are sandblasted and epoxy coated for additional corrosion protection. On request an additional zinc anode can be inserted into the headers. Floating and fixed tube bundle arrangements are all standard. To further improve heat transfer the thinnest possible tube walling is employed and “dead areas” avoided to the fullest extent possible.

### 3.4.1 Tubes

**Figure 22 – Shell-and-tube JAD**



**Source – Secespol – CZ, s.r.o.**

Tubing may be seamless or welded. Seamless tubing is produced in an extrusion process; welded tubing is produced by rolling a strip into a cylinder and welding the seam. Welded tubing is usually more economical.

Tubing may be finned to provide more heat transfer surface; finning is more common on the outside of the tubes, but is also available on the inside of the tubes. High flux tubes are tubing with special surface to enhance heat transfer on either or both sides of the tube wall. Inserts such as twisted tapes can be installed inside tubes to improve heat transfer especially when handling viscous fluids in laminar flow conditions. Twisted tubes are also available. These tubes can provide enhanced heat transfer in certain applications.

### 3.4.2 Tubesheets

Tubesheets are plates or forgings drilled to provide holes through which tubes are inserted. Tubes are appropriately secured to the tubesheet so that the fluid on the shell side is prevented from mixing with the fluid on the tube side. Holes are drilled in the tubesheet normally in either of two patterns, triangular or square. Triangular pitch is most often applied because of higher heat transfer and compactness it provides. Square pitch facilitates mechanical cleaning of the outside of the tubes.

### 3.4.3 Baffles

Baffles serve three functions:

- support the tube
- maintain the tube spacing
- direct the flow of fluid in the desired pattern through the shell side

A segment, called the baffle cut, is cut away to permit the fluid to flow parallel to the tube axis as it flows from one baffle space to another. Segmental cuts with the height of the segment approximately 25 percent of the shell diameter are normally the optimum. Baffle cuts larger or smaller than the optimum typically result in poorly distributed shell side flow with large eddies, dead zones behind the baffles and pressure drops higher than expected.

The spacing between segmental baffles is called the baffle pitch. The baffle pitch and the baffle cut determine the cross flow velocity and hence the rate of heat transfer and the pressure drop. The baffle pitch and baffle cut are selected during the heat exchanger design to yield the highest fluid velocity and heat transfer rate while respecting the allowable pressure drop.

### 3.4.4 Tie rods and spacers

Tie rods and spacers are used for two reasons:

- hold the baffle assembly together
- maintain the selected baffle spacing

The tie rods are secured at one end to the tubesheet and at the other end to the last baffle. They hold the baffle assembly together. The spacers are placed over the tie rods between each baffle to maintain the selected baffle pitch. The minimum number of tie rod and spacers depends on the diameter of the shell and the size of the tie rod and spacers.

### 3.4.5 Channels (Heads)

Channels or heads are required for shell-and-tube heat exchangers to contain the tube side fluid and to provide the desired flow path. Many types of channels are available.

# 4 Materials and methods

## 4.1 Study cases for assessment

The plate exchangers used for the assessment of usability of copper brazed plate heat exchangers included 4 plate exchangers by Alfa Laval, s.r.o. and 4 shell-and-tube exchangers by Secespol – CZ, s.r.o. Technical specifications of the shell-and-tube exchangers (see Attachments 7 - 10) are in Czech only as it was not possible to obtain them in English. The life service is defined as 8 years for all the exchangers.

Heat plants in the Czech Republic used to have shell-and-tube heat exchangers, but this thesis should demonstrate, that plate heat exchangers are more efficient and save costs, energy and environmental.

### 4.1.1 Criteria applied in the tables

This chapter describes in detail the criteria used to assess the best exchangers within certain categories.

- Temperature difference in return line (TD)
  This figure expresses the difference in temperature between the exchangers at the output from the primary circuit. It is an important indicator as the exchanger able to cool the liquid down to a lower temperature level saves energy and pumping works of heat plant and is more efficient. Save the cost. The values are defined in °C.
  The weight of this criterion is 15%.
- Hold-up volume ($V_m$)
  The size of the hold-up volume affects the speed of regulation. Heat exchanger with large hold-up volume has a slower response to a change of the power demand (decrease / increase) than in the heat exchanger with small hold-up volume.
  Hold-up volume for plate heat exchangers from Alfa Laval is obtained by subtracting the empty weight from the operating weight and divided by two for the hold-up on one side. Those parameters are shown in technical specifications in the attachments 3-6. Hold-up of shell-and-tube heat exchangers is taken "Objem trubkovice" (Attachments 7-10).
  The weight of this criterion is 10%.

- Heat transfer coefficient (k)

  This quantity is described in detail in Chapter 3.2.3.

  The weight of this criterion is 10%.

- Anchoring (AN)

  This is a subjective but still very important indicator. It entails the method of connection of the exchanger and it is based on the assessment of the work and time necessary for its assembly and disassembly. An exchanger with threaded anchoring and four outlets is ranked by full 5 points because the manipulation is very easy is only involves placing the exchanger onto the tubes and tightening the thread. On the other hand, for exchangers with a neck/flat flange, the time necessary for installation is longer and it entails more work as it is necessary to anchor the device using special tools and holes in various directions. An exchanger of such a design will be ranked as 2.

  The weight of this criterion is 10%.

- Mass (m)

  The mass is defined as a value expressing the level of inertial and gravitational effects invoked by two solids influencing one another. In the SI system, it is expressed in kilograms.

  The weight of this criterion is 10%.

- Area (A)

  Here is provides the ground area of the exchanger to allow the calculation the area occupied by 1 exchanger. It is expressed in square meters. This figure is important for the calculation of costs for space.

  The weight of this criterion is 10%.

- Costs (C)

  The amount provided in the costs will comprise the total amount for purchasing the exchangers. All costs for heat exchangers are provided in EUR.

  The weight of this criterion is 35%.

  The resulting total costs are equal to the product of the following partial costs:

  - Purchase costs ($C_p$) - the most significant portion of the total costs; it has been determined as the cost of exchanger replacement charged by relevant companies as of 5th March 2015.
  - Inspection costs ($C_i$) - the ČSN 69 0012 standard implies that a plate exchanger is not subject to inspection duty while shell-and-tube exchangers not. For such

exchangers, one operational inspection is mandatory once a year as a minimum. For the calculation of inspection costs over the 8-year service life of the exchanger, a single constant inflation rate shall be determined as the arithmetic average value. Inflation rate as an increase in average annual CPI indicates percentage change in last 12-month average over preceding 12-month average. This inflation rate is appropriate for making adjustments or considerations of average quantities (Czech Statistical Office). To calculate this constant, figures for 2007-2014 will be used. The Inflation rate provided by the Czech Statistical Office is used: 2007 – 2, 80%; 2008 – 6, 30%; 2009 – 1, 00%; 2010 – 1, 50%; 2011 – 1, 90%; 2012 – 3, 30%; 2013 – 1, 40%; 2014 – 0, 40% (Czech Statistical Office). The constant calculated as the arithmetic average of these values is equal to 2.33%. The inspection costs will be increased by this inflation rate every year. The price of one inspection in 2015 is 1 750 CZK (private service provider). This amount is converted to EUR using the exchange rate of 27.29 CZK/EUR (Czech National Bank).For the following 7 years (to determine the total costs for the Inspection costs), the same inflation rate constant as for the inspection costs is used. The overview of the costs for space for 2015-2022 is provided in Table 1.

**Table 1 – Inspection costs**

| Year | $C_i$ [EUR] |
|---|---:|
| 2015 | 64, 13 |
| 2016 | 65, 62 |
| 2017 | 67, 14 |
| 2018 | 68, 70 |
| 2019 | 70, 30 |
| 2020 | 71, 94 |
| 2021 | 73, 61 |
| 2022 | 75, 32 |
| **Total** | **556, 75** |

**Source – Michal Janča**

- Costs for space ($C_s$) - this cost portion is important in terms of the exchanger's operation. It is the cost for one exchanger within the production process. The cost for space itself is strongly individual and cannot be determined per area; for this specific case and for determination of the costs provided in the table, the facility intended for production was selected. It is located at the address Za Mototechnou, Prague 5. The building is leased for 135 CZK/$m^2$/month (Netrealit.cz*)*. This amount is converted to EUR using the exchange rate of 27.29 CZK/EUR (Czech National Bank). In 2015, the lease amounts to EUR 59.40 per 1 $m^2$ (4.95 EUR/$m^2$/month *12). For the following 7 years (to determine the total costs for the exchanger area), the same inflation rate constant as for the inspection costs is used. The overview of the costs for space for 2015-2022 is provided in Table 2.

**Table 2 – Inflation rate**

| **Year** | **$C_s$ [EUR/$m^2$]** |
|---|---|
| 2015 | 59, 40 |
| 2016 | 60, 78 |
| 2017 | 62, 20 |
| 2018 | 63, 65 |
| 2019 | 65, 13 |
| 2020 | 66, 65 |
| 2021 | 68, 20 |
| 2022 | 69, 79 |
| **Total** | **515, 81** |

**Source – Michal Janča**

Table 2 implies that the costs for 1 $m^2$ over the 8-year service life of the exchanger amounts to EUR 515.81. This amount has been multiplied by the ground area of the exchanger to determine the final unit costs.

This process resulted in the establishment of 4 categories for the assessment of 1 copper brazed plate exchanger in comparison with 1 shell-and-tube exchanger.

### 4.1.2 First category

In this category (Table 3) are exchangers with output of 250 kW for water cooling from 130°C down to 65°C.

- Copper brazed plate heat exchanger CB 110-30M (Alfa Laval, s.r.o.) - for technical data, see Attachment No. 3
- Shell-and-tube heat exchanger JAD X 5.38 MF.STA.CS (Secespol – CZ, s.r.o.) - for technical data, see Attachment No. 7

**Table 3 – Exchangers with output of 250 kW, water cooling from 130°C down to 65°C**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | Costs [EUR] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $C_p$ | $C_i$ | $C_s$ | C |
| **CB 110-30M** | 0,00 | 2,95 | 4615,00 | Thread | 19,40 | 0,02 | 2 142 | 0 | 9 | 2 151 |
| **JAD X 5.38 MF.STA.CS** | 1,60 | 6,60 | 3326,90 | Neck/flat flange | 41,70 | 0,04 | 1 378 | 557 | 23 | 1 957 |

**Source – Michal Janča**

### 4.1.3 Second category

In this category (Table 4) are exchangers with output of 500 kW for water cooling from 130°C down to 65°C.

- Copper brazed plate heat exchanger CB 110-64M (Alfa Laval, s.r.o.) - for technical data, see Attachment No. 4
- Shell-and-tube heat exchanger JAD X 9.88 MF.STA.CS (Secespol – CZ, s.r.o.) - for technical data, see Attachment No. 8

**Table 4 – Exchangers with output of 500 kW, water cooling from 130°C down to 65°C**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | Costs [EUR] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $C_p$ | $C_i$ | $C_s$ | C |
| **CB110-64M** | 0,00 | 6,40 | 4373,00 | Thread | 31,50 | 0,03 | 3 610 | 0 | 18 | 3 628 |
| **JAD X 9.88 MF.STA.CS** | 2,20 | 16,00 | 2578,60 | Neck/flat flange | 98,00 | 0,09 | 2 103 | 557 | 47 | 2 706 |

**Source – Michal Janča**

### 4.1.4 Third category

In this category (Table 5) are exchangers with output of 250 kW for water cooling from 80°C down to 25°C.

- Fusion-bonded plate heat exchanger AlfaNova 76-30H (Alfa Laval, s.r.o.) - for technical data, see Attachment No. 5
- Shell-and-tube heat exchanger JAD X 12.114 MF.STA.CS 250 (Secespol – CZ, s.r.o.) - for technical data, see Attachment No. 9

**Table 5 – Exchangers with output of 250 kW, water cooling from 80°C down to 25°C**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | Costs [EUR] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $C_p$ | $C_i$ | $C_s$ | C |
| **AlfaNova 76-30H** | 0,00 | 3,60 | 4808,00 | Thread | 23,80 | 0,02 | 3 274 | 0 | 10 | 3 284 |
| **JAD X 12.114 MF.STA.CS 250** | 2,20 | 20,10 | 686,90 | Neck/flat flange | 156,00 | 0,13 | 5 283 | 557 | 68 | 5 908 |

**Source – Michal Janča**

### 4.1.5 Fourth category

In this category (Table 6) are exchangers with output of 500 kW for water cooling from 80°C down to 25°C.

- Fusion-bonded plate heat exchanger AlfaNova 76-50H (Alfa Laval, s.r.o.) - for technical data, see Attachment No. 6
- Shell-and-tube heat exchanger JAD X 12.114 MF.STA.CS 500 (Secespol – CZ, s.r.o.) - for technical data, see Attachment No. 10

**Table 6 – Exchangers with output of 500 kW, water cooling from 80°C down to 25°C**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | Costs [EUR] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $C_p$ | $C_i$ | $C_s$ | C |
| **AlfaNova 76-50H** | 0,00 | 6,05 | 5402,00 | Thread | 33,80 | 0,03 | 4 551 | 0 | 15 | 4 566 |
| **JAD X 12.114 MF.STA.CS 500** | 5,40 | 20,10 | 1213,10 | Neck/flat flange | 156,00 | 0,13 | 5 283 | 557 | 68 | 5 908 |

**Source – Michal Janča**

### 4.1.6 Weighted sum product - WSA

The Weighted sum product method is used in Chapter 5.1 to evaluate the best suitable exchanger based on the selected criteria.

First of all, it is necessary to classify the variants using the criteria (the maximum being 5 points, minimum 0. The points are expressed as percentage). Then the data can be arranged in the criteria matrix Y = ($y_{ij}$). The elements in this matrix express the assessment of the $i^{th}$ variant based on the $j^{th}$ criterion. The matrix rows correspond to variants, while the matrix columns correspond to the criteria. The criteria can be divided into maximizing criteria (the higher value, the better ranking) and minimizing criteria (the lower value, the better ranking). To get a better idea of the quality of individual variants, it is also useful to know the best/the worst theoretical variant. The first of them, i.e. the variant achieving the best values in all criteria, is called the ideal variant, while the variant with all the criteria values at the lower level is called the basal variant (Brožová et al., 2003).

As per Brožová et al. (2003), the method is based on the calculation of so-called utility function for each variant. Its functional values range from 0 to 1; a higher value means a more beneficial variant. The procedure of the mentioned method is as follows:

- Convert the minimizing criteria to maximizing criteria. This can be done by subtracting individual elements in the minimizing criteria columns from the maximum element in given column. Thus it was find out by how much the variant in question is better than the worst case variant based on given criterion. To simplify the explanation, it will still refer to the resulting transformed criteria matrix as Y (with elements $y_{ij}$).
- Now it need to be determine the ideal variant H and basal variant D.
- Let create a standardized criteria matrix R, whose elements can be calculate using the formula

$$r_{ij} = (y_{ij} - D_j)/(H_j - D_j)$$

- For individual variants (referring to the i-th variant as $a_i$), calculate the utility function

$$u(a_i) = \sum_{j=1}^{k} v_j r_{ij}$$

  where $v_j$ are the weights of individual criteria.

- Now can be sort the variants in descending order by the utility function.

### 4.2 Specific case in one heating plant

The První Mostecká a.s. company used to has shell-and-tube heat exchangers. Based on the recommendations of the selling company switched the technology to copper brazed plate heat exchangers. With these new exchangers occurred problems because they couldn't withstand the lifetime and failed to fulfil a return on investment tap water circuit.

The company requested review for the reason of limited life service of copper brazed plate exchangers at the Most location. The task consisted in determination of damage of the plate exchangers and possible causes of this damage.

It is widely known that many properties of materials are related to the composition of their surfaces. The physical and chemical properties of the surface influence factors such as corrosion rate, hydrophobic or hydrophilic parameters as well as wear level and abrasion, which determine the life service of all operational tools or parts. This is why in a number of technological and research branches, the study of “superficial chemistry” is more and more important.

### 4.2.1 Preparation of samples from exchangers

Two exchangers were analysed:

- CBH76-80M (for technical data, see Attachment No. 1)
- CBH200 (for technical data, see Attachment No. 2)

**Figure 23 – Sample of exchanger CBH76-80M**

**Source – Alfa Laval, s.r.o.**

The units have been in service in a district heating application for approximately 5 years. The primary circuit is the hot tap water circuit, while the secondary circuit is the district heating or intermediate circuit for domestic heating and subsequent hot tap water preparation. The exchangers serve for heat transfer from the heat station circuit either to the hot service water circuit or to the intermediate circuit mentioned above.

The exchanger CBH76-80M was cut into several parts; from the smaller part, a subpart was cut off, which was further cut into smaller parts - see Figure 23. During cutting of the exchanger, parts of corrosive products were released from the internal surfaces in the form of dust as well as larger particles as small lamellas and nodules - these were probably agglomerates of smaller particles.

# 5 Results

## 5.1 Results of study cases

To assess copper brazed plate exchangers in the conditions of the Czech Republic, two companies operating on the heat exchanger market were included:

- Alfa Laval, s.r.o.
- Secespol - CZ, s.r.o.

These companies were asked to design plate and shell-and-tube exchangers for four identical projects; the companies sent the quotes for the specific exchangers so as to allow a comprehensive comparison based on the parameters provided in Chapter 4.1.1. The heat exchangers are intended for a wide range of applications of heat supply in heavy industry, food industry and, above all, junction exchange stations. Heat energy supply forms in integral part of the energy sector of the national economy and the energy infrastructure of cities and municipalities. As a business sector, it meets the basic needs of citizens that include ensuring thermal comfort and hot tap water supply. It supplies heat energy to commercial and public sector including schools, offices and medical centres. District heating constitutes the essential condition for wide deployment of high-efficient combined heat and power technology that substantially saves primary energy. Due to those savings and the opportunity to use a broad range of primary energy sources, including domestic fuels and, renewable and secondary sources, it plays an indispensable role in ensuring the energy security and independence of the Czech Republic. District heating also contributes to environmental protection. Heat energy supply helps reduce air pollution in urban areas.

Table 7 summarizes all companies operating on Czech market, which produce heat, and their boiler capacity. The table specifies the heat supplied from power plants and heat stations at the interface between the boiler room and machine room; in case of heating plants and separate boiler rooms (at the outlet), only heat produced from operating sources (including leased sources), omitting heat purchased from external sources. Table 7 shows the potential use of heat exchangers in the conditions of the Czech Republic. První Mostecká a.s. is a member of the United Energy, a.s. association.

**Table 7 – Heat producers**

| Heat producers | Heat produced (boiler) [GJ] |
|---|---|
| ACTHERM spol. s.r.o. | **1 341 111** |
| Alppiq Generation (CZ) s.r.o. | **17 463 123** |
| ArcelorMittal Frýdek – Místek a.s. | **346 542** |
| C-Energy Bohemia s.r.o. | **1 734 853** |
| Centrální zdroj tepla Dobruška, a.s. | **73 204** |
| ČEZ, a.s. | **572 263 583** |
| Dalkia Česká republika, a.s. | **15 086 087** |
| DOTERM SERVIS s.r.o. – právní nástupce | **116 059** |
| E.ON Trend s.r.o. | **263 545** |
| Elektrárna Chvaletice a.s. | **27 439 106** |
| Elektrárny Opatovice, a.s. | **21 265 002** |
| Energetika Třinec, a.s. | **11 444 323** |
| ENERGOAQUA, a.s. | **257 677** |
| KH TEBIS s.r.o. | **92 210** |
| KLATOVSKÁ TEPLÁRNA a.s. | **261 556** |
| KOMTERM, a.s. | **1 592 598** |
| MH Energo s.r.o. | **224 385** |
| MVV Energie CZ a.s. | **5 060 485** |
| Ostrovská teplárenská, a.s. | **435 994** |
| Plzeňská teplárenská, a.s. | **8 637 302** |
| Pražská teplárenská a.s. | **3 863 000** |
| RWE Energo, s.r.o. | **980 622** |
| Služby města Postoloprty, s.r.o. | **28 082** |
| ŠKO – ENERGO, s.r.o. | **5 148 755** |
| TAMERO INVEST s.r.o. | **6 046 986** |
| Teplárna České Budějovice, a.s. | **3 415 459** |
| Teplárna Kyjov, a.s. | **188 713** |
| Teplárna Otrokovice a.s. | **3 647 920** |
| Teplárna Písek, a.s. | **554 484** |
| Teplárna Strakonice, a.s. | **1 823 590** |
| Teplárna Tábor, a.s. | **1 746 568** |
| Teplárny Brno, a.s. | **5 086 659** |
| TEPLO BRUNTÁL a.s. | **514 848** |
| Thermoservis, spol. s.r.o. | **227 000** |
| TTS energo s.r.o. | **363 732** |
| United Energy, a.s. | **10 046 522** |
| Zásobování teplem s.r.o. Blansko | **241 436** |

**Source – Association for District Heating of the Czech Republic**

Table 8 shows the results for the first category, see Chapter 4.1.2. The results are ranked by 5 points maximum (5 points for the best option based on given criterion); the second value has been calculated as the percentage difference between the actual values. The ranking system is identical for all of the 4 groups. All calculations used in the thesis are provided in Attachment No. 11.

The table also shows the character of individual criteria, their weights and ideal/basic options, which are necessary to compile the final table for the assessment of the exchangers.

**Table 8 – Score of table 3**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | C [EUR] |
|---|---|---|---|---|---|---|---|
| **CB 110-30M** | 0,00 | 2,23 | 5,00 | 5,00 | 2,33 | 1,99 | 5,00 |
| **JAD X 5.38 MF.STA.CS** | 5,00 | 5,00 | 3,60 | 2,00 | 5,00 | 5,00 | 4,55 |
| **Criteria** | MIN | MIN | MAX | MAX | MIN | MIN | MIN |
| **Weight** | 0,15 | 0,10 | 0,10 | 0,10 | 0,10 | 0,10 | 0,35 |
| **Ideal** | 0,00 | 2,23 | 5,00 | 5,00 | 2,33 | 1,99 | 4,55 |
| **Basal** | 5,00 | 5,00 | 3,60 | 2,00 | 5,00 | 5,00 | 5,00 |

**Source – Michal Janča**

In Table 9, individual criteria are assessed; 1 means that the exchanger is the winner in the category, while 0 means that it has been unsuccessful. With regard to the weights used, the CB 110-30M brazed plate heat exchanger ranked better with 55% than the JAD X 5.38 MF.STA.CS shell-and-tube exchanger with 45%.

**Table 9 – First variant sorted by the utility function**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | C [EUR] | Utility | Rank |
|---|---|---|---|---|---|---|---|---|---|
| **CB 110-30M** | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,00 | 0,65 | **1** |
| **JAD X 5.38 MF.STA.CS** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,35 | **2** |

**Source – Michal Janča**

Table 10 shows the point ranking of the exchanger group provided in Chapter 4.1.3. These exchanger models are designed for the output of 500 kW.

**Table 10 – Score of table 4**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | C [EUR] |
|---|---|---|---|---|---|---|---|
| **CB110-64M** | 0,00 | 2,00 | 5,00 | 5,00 | 1,61 | 1,88 | 5,00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **JAD X 9.88 MF.STA.CS** | 5,00 | 5,00 | 2,95 | 2,00 | 5,00 | 5,00 | 3,73 |
| **Criteria** | MIN | MIN | MAX | MAX | MIN | MIN | MIN |
| **Weight** | 0,15 | 0,10 | 0,10 | 0,10 | 0,10 | 0,10 | 0,35 |
| **Ideal** | 0,00 | 2,00 | 5,00 | 5,00 | 1,61 | 1,88 | 3,73 |
| **Basal** | 5,00 | 5,00 | 2,95 | 2,00 | 5,00 | 5,00 | 5,00 |

**Source – Michal Janča**

The final Table 11 for the second category implies that the copper brazed plate heat exchanger CB110-64M is more efficient than the plate exchanger JAD X 9.88 MF.STA.CS; the ratio is 65% / 35%. In this category, the plate exchanger wins in all aspects except for the unit costs (per single exchanger).

**Table 11 – Second variant sorted by the utility function**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | C [EUR] | Utility | Rank |
|---|---|---|---|---|---|---|---|---|---|
| **CB110-64M** | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,00 | 0,65 | **1** |
| **JAD X 9.88 MF.STA.CS** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,35 | **2** |

**Source – Michal Janča**

The third category (see Chapter 4.1.4) is summarized in Tables 12 and 13. Table 12 shows the ranking of the criteria and the final Table 13 shows that the fusion-bonded plate exchanger AlfaNova 76-30 H wins over the shell-and-tube exchanger JAD X 12.114 MF.STASC 250 in all aspects. Exchanger of this type is cheaper and moreover, more advanced than the shell-and-tube exchanger.

**Table 12 – Score of table 5**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | C [EUR] |
|---|---|---|---|---|---|---|---|
| **AlfaNova 76-30H** | 0,00 | 0,90 | 5,00 | 5,00 | 0,76 | 0,70 | 2,78 |
| **JAD X 12.114 MF.STA.CS 250** | 5,00 | 5,00 | 0,71 | 2,00 | 5,00 | 5,00 | 5,00 |
| **Criteria** | MIN | MIN | MAX | MAX | MIN | MIN | MIN |
| **Weight** | 0,15 | 0,10 | 0,10 | 0,10 | 0,10 | 0,10 | 0,35 |
| **Ideal** | 0,00 | 0,90 | 5,00 | 5,00 | 0,76 | 0,70 | 2,78 |
| **Basal** | 5,00 | 5,00 | 0,71 | 2,00 | 5,00 | 5,00 | 5,00 |

**Source – Michal Janča**

**Table 13 – Third variant sorted by the utility function**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | C [EUR] | Utility | Rank |
|---|---|---|---|---|---|---|---|---|---|
| **AlfaNova 76-30H** | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1 | **1** |
| **JAD X 12.114 MF.STA.CS 250** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0 | **2** |

**Source – Michal Janča**

The fourth category (see Chapter 4.1.5) includes heat exchangers with doubled output compared to the previous category. It amounts to 500 kW. Table 14 summarizes the ranked criteria again, while Table 15 provided assessment of individual criteria and evaluation of the most efficient exchanger. The plate exchanger AlfaNova 76-50H surpasses the shell-and-tube exchanger JAD X 12.114 MF.STA.CS 500 in all aspects.

**Table 14 – Score of table 6**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | C [EUR] |
|---|---|---|---|---|---|---|---|
| **AlfaNova 76-50H** | 0,00 | 1,50 | 5,00 | 5,00 | 1,08 | 1,11 | 3,86 |
| **JAD X 12.114 MF.STA.CS 500** | 5,00 | 5,00 | 1,12 | 2,00 | 5,00 | 5,00 | 5,00 |
| **Criteria** | MIN | MIN | MAX | MAX | MIN | MIN | MIN |
| **Weight** | 0,15 | 0,10 | 0,10 | 0,10 | 0,10 | 0,10 | 0,35 |
| **Ideal** | 0,00 | 1,50 | 5,00 | 5,00 | 1,08 | 1,11 | 3,86 |
| **Basal** | 5,00 | 5,00 | 1,12 | 2,00 | 5,00 | 5,00 | 5,00 |

**Source – Michal Janča**

**Table 15 – Fourth variant sorted by the utility function**

| Model | TD [°C] | $V_m$ [l] | k [W*m$^{-2}$*K$^{-1}$] | AN [-] | m [kg] | A [m$^2$] | C [EUR] | Utility | Rank |
|---|---|---|---|---|---|---|---|---|---|
| **AlfaNova 76-50H** | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1 | **1** |
| **JAD X 12.114 MF.STA.CS 500** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0 | **2** |

**Source – Michal Janča**

## 5.2 Results of a specific case in one heating plant

### 5.2.1 Heat exchanger CBH76-80M

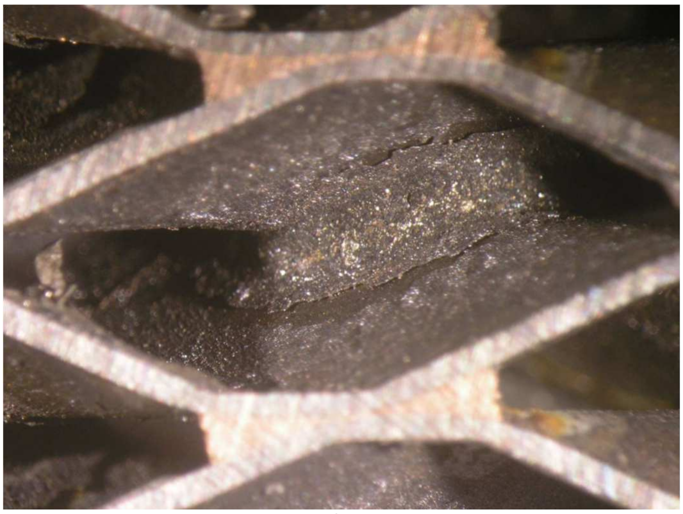
The condition of copper joints is, in terms of corrosion level, similar on both the primary and secondary sides of the exchanger; this means that none of the sides shows considerably higher corrosion level compared to the other one - see the condition of joints on figures 24 and 25. However, the character of corrosion is different in terms of structure.

**Figure 24 – Joint on primary side**

**Source – Alfa Laval, s.r.o.**

The primary side (Figure 24) shows corrosion products and coloration around the joint, with parts of the layer visibly peeled off. The joints are corroded rather across the surface, i.e. homogeneously, while the corrosion products contain (in certain cases) a considerable amount of iron, with a presence of sulphur. It can assume that the dark surface layer on the primary side consists mainly of Cu and Fe oxides.

**Figure 25 – Joint on secondary side**



**Source – Alfa Laval, s.r.o.**

On the secondary side (Figure 25), is visible corrosion products around the joint of silvery colour, with a tendency for peeling off. The joints on the secondary side are rather corroded along the grain boundaries.

**Chemical reactions of the copper corrosion process under given conditions in the secondary circuits**

In case a sulphite is used for chemical degasification, the following reaction will occur. The saturated solution of sodium sulphite has pH = 9; this means that the first step in the water solution will be dissociation:

$$H_2O + Na_2SO_3 \rightarrow 2Na^+ + OH^- + HSO_3^- \qquad (5.1)$$

The reaction itself proceeds as follows:

$$4Cu + HSO_3^- \rightarrow Cu_2S + 2\ CuO + OH^- \qquad (5.2)$$

Or:

$$3Cu + HSO_3^- \rightarrow CuS + 2\ CuO + OH^- \qquad (5.3)$$

As far as copper disulphide $Cu_2S$ is concerned, it is noted (5.2) that it is a “dark-lead grey crystallise powder”, which exactly correspond to the substances found on the copper surfaces.

Copper monosulphide CuS is known (5.3) to be a “black or blue-black powder, after pulverization of indigo blue colour”. The blue corrosion product was found very rarely on the primary side; therefore the first option (as per equation 5.2) appears to be more probable.

Detailed determination of compounds present would be possible with a more extensive research using namely diffraction methods; for this purpose however, a larger amount of pure corrosion products would be necessary, which is difficult due to the exchanger design.

The character of copper corrosion clearly shows that the major problem is local corrosion of copper joints on the secondary side of the exchanger, which leads to faster destruction of the joint.

The life service of the exchanger can be improved by limiting the presence of sulphur content in the circuits; namely in the secondary part, limiting the sulphite and sulphate content should considerable improve the situation.

### 5.2.2 Heat exchanger CBH200

**Figure 26 – The researched heat exchanger seen from frame plate (a) and pressure plate (b)**


**Source – Alfa Laval, s.r.o.**

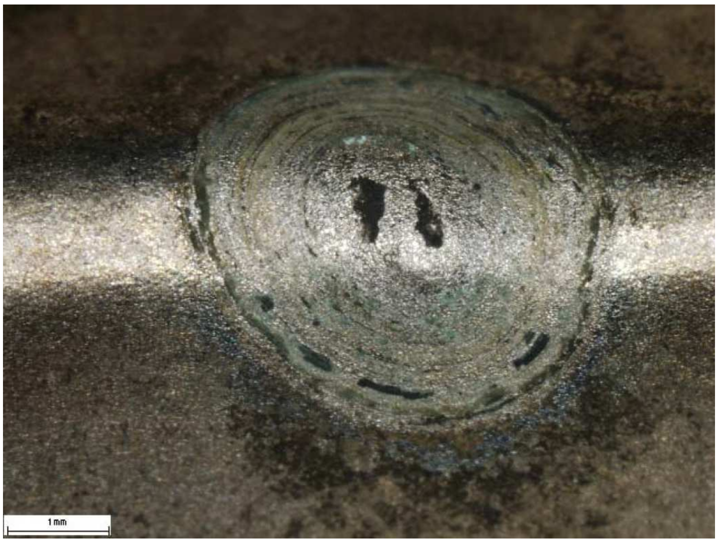
The investigated CBH200 unit (displayed in figure 26a and b) has failed due to general corrosion of the cooper brazing filler material in the secondary side (district heating side, S3-S4). Massive plastic deformations in the pressure plate and adjacent channel plates were detected (26b). The position of the large external leak has been indicated by arrow.

**Figure 27 – Cut out section of the unit showing plastic deformation within the unit**

**Source – Alfa Laval, s.r.o.**

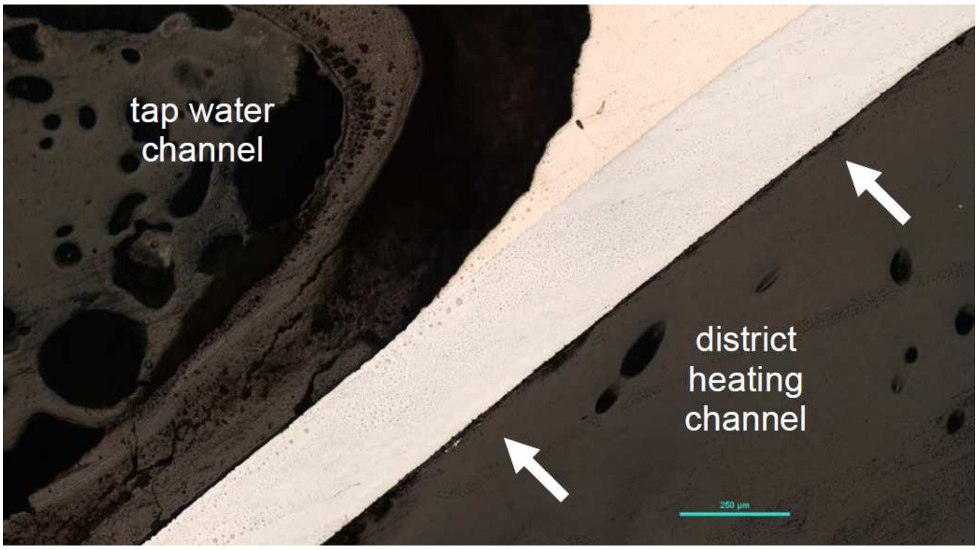
When the unit was cut open, the lack of brazing joints at contact points of the channel plates in the secondary side (district heating side, S3-S4) of the unit became obvious (Figure 27). Residues of black corrosion products were found within the secondary side of the unit mainly accumulated at the brazing joints which remained. At areas where the brazing joints had been entirely removed, consecutively smaller dark circles at the base of the brazing joints had formed (Figure 28).

**Figure 28 – The base area of a corroded copper brazing**




**Source – Alfa Laval, s.r.o.**

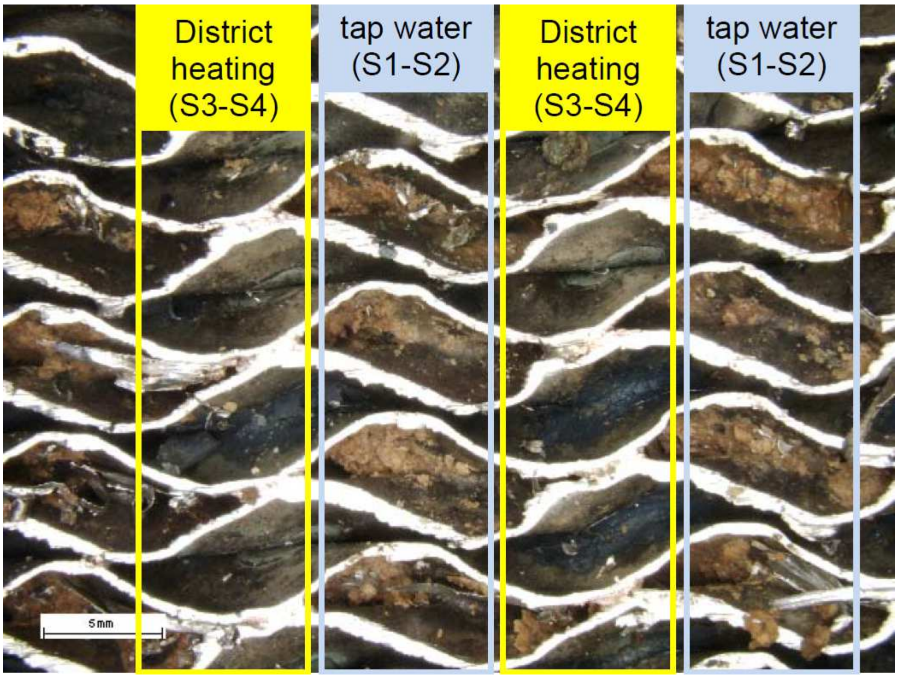
**Figure 29 – The metallographic cross section**




**Source– Alfa Laval, s.r.o.**

The metallographic cross section revealed no corrosive attacks on the channel plate material. Cross section from the interior in figure 29 showing a smooth exterior of the plate material free from intergranular corrosive attacks on the S3-S4 (district heating) side of the unit (indicated by arrows)

**Figure 30 – Detail on district heating sides and hot tap water sides**




**Source– Alfa Laval, s.r.o.**

Large amounts of carbonate scale fouling were wound in the primary circuit (tap water side, S1-S2) (Figure 30), which were indicated by chemical testing using hydrochloric acid. Missing and corroded brazing joints are also seen on the S3-S4 (district heating) side.

The investigated CBH200 unit has failed due to general corrosion of the copper brazing filler material in the secondary side (district heating side, S3-S4).

The magnitude of corrosion of brazing joints has reduced the ability of the unit to withstand internal pressure which has resulted in plastic deformations of the stabilizing pressure plate. Ultimately the tensile load on the overlapping flanks of the stacked channel plates has resulted in rupture and external leakage.

On the secondary side of the unit indicated alarmingly high levels of sulphur in the district heating water. After formation at the brazing joints within the unit, copper sulphide compounds have most likely been removed by the flow of surrounding media. This has lead to exposure of pure copper followed again by corrosion. The subsequent corrosion and removal of formed products leads to a sequential diminishing of the copper brazing joints at contact points between channel plates within the unit.

No manufacturing defects could be found on the exterior or within the unit it can be definitely conclude that the reduced service life of the exchanger CBH200 was caused by higher sulphur content in the secondary circuit; this is the reason why the planned life service of the exchanger was not met. As a conclusion, a chemical analysis of water can be recommended in given area as well as determination of the source of sulphur content and its reduction, or considering the use of different exchangers, which would eliminate any further corrosion risks.

# 6 Discussion

Much research has been carried out in this area. In such optimization activities, some researchers utilize objective functions aimed at decreasing total cost and heat transfer area (Sadeghzadeha, Ehyaeib and Rosenc, 2015). In this thesis are used many parameters for determining optimal selection of right heat exchanger.

The selection of a heat exchanger of suitable type is an important stage of the process and equipment design. In many industrial applications, shell-and-tube exchangers are still often selected automatically; they can be used for any operational conditions (temperature, pressure) and there are very good and well-proven calculation procedures available for their design. However, other types of exchangers can be more suitable for many applications. This thesis concentrates on copper brazed heat exchangers to present their benefits compared to other exchangers and explore their technical parameters in specific cases.

## 6.1 Assessment of copper brazed plate heat exchangers in the conditions of the Czech Republic

Since economical operation is one of the basic criteria for the selection of a heat exchanger, correct economical assessment is often a very difficult task with relatively uncertain results. As the input to this calculation, a number of parameters can be used, of which certain part has a large value range, which cannot be verified before the practical implementation. That is why it is probably impossible to take into account just the numerical results of the economical parameters; other analyses are also needed. For this purpose, a group of parameters was established for the comparison of selected exchangers; based on these parameters, the most efficient heat exchanger for each category should be determined. The costs, which are of course a major aspect in these times of a tough competition on almost all markets, are of major significance here, but they are not essential. The costs for the exchanger were calculated based on its purchase price, costs for regular inspections and space occupied by the exchanger in the building. Heat stations and all subjects working with heat recovery are well aware that the price is not the most important factor when purchasing new heat exchangers. It is important to point out that the cost table takes into account a single exchanger only; in practice, there are projects far exceeding the number of one exchanger.

Other important criteria for the selection of an exchanger included the temperature difference in the return line, hold-up volume, heat transfer coefficient, anchoring, mass and ground area. The criteria used as well as their weight are very subjective and it is up to the party ordering the delivery to establish the criteria for the selection of exchanger of a specific type. However, this procedure is recommended in case of a project for a new heat exchanger. Using the procedure offered here, every interested person will be able to get an overview of the exchanger market, whether for commercial or personal use.

The thesis establishes 4 categories, which include one plate exchanger and one shell-and-tube exchanger each, to be assessed based on the selected criteria.

The first category involved the comparison of the copper brazed plate exchanger CB 110-30M and welded shell-and-tube exchanger JAD X 5.38 MF.STA.CS. The values in Table 3 show that the major advantage of the JAD X 5.38 MF.STA.CS exchanger is its purchase price. On the other hand, in terms of other costs, it is the CB 110-30M exchanger which is more efficient. The WSA method and Table 9 shows that the plate exchanger is more efficient than shell-and-tube exchanger; the ratio is 55/45. In practice, we can say that the plate exchanger can be recommended in this category in spite of higher purchase costs.

This category involves assessment of the copper brazed plate heat exchanger CB110-64M compared to the welded shell-and-tube exchanger JAD X 9.88 MF.STA.CS. Here the purchase price is also lower for the shell-and-tube exchanger than for the plate exchanger (Table 4). However, table 11 implies that the copper brazed plate exchanger is more efficient with a ratio of 65/35. In this category, the plate exchanger can also be recommended.

The third category involves assessment of the fusion-bonded plate heat exchanger AlfaNova 76-30H compared to the welded shell-and-tube exchanger JAD X 12.114 MF.STA.CS 250. Here, however, the plate exchanger is less expensive than the shell-and-tube exchanger (Table 5); based on the selected criteria, it is more efficient with a ratio of 100:0 (Table 12).

The last category includes the fusion-bonded exchanger AlfaNova 76-50H and welded shell-and-tube exchanger JAD X 12.114 MF.STA.CS 500. Here the results are similar to the previous category; the plate exchanger is more efficient with a ratio of 100:0 (Table 13).

In all the selected categories, the plate exchanger is more efficient, namely due to better technical parameters: higher energy efficiency, more compact and easier to manipulate as well as overall environmental impacts.

The selection of the correct type is important to avoid selection of improper technology. Copper brazed plate exchangers are less expensive than fusion-bonded plate exchangers (see Tables 3-6); however, the specific application must be taken into account. As shown in Chapter 6.2, where copper brazed plate exchangers were deteriorated by the effects of water with high sulphur content, all aspects need to be taken into account when selecting the exchanger.

Walravena, Laenenb and D'haeseleera (2014) say: "it is shown that all plate heat exchangers perform mostly better than shell-and-tube heat exchangers." Similar result is also in this thesis, when plate heat exchangers were better than shell-and-tube heat exchangers in all four categories.

## 6.2 Evaluation of a specific case in one heating plant with assessment of suitability of implementation of copper brazed heat exchangers for hot tap water production and district heating

This thesis concentrates on a specific case, where copper brazed exchangers were damaged after 5 years of operation at První Mostecká a.s. The examined exchangers included the CBH76-80M and CBH200 models. At both exchangers, the copper brazed joints at the secondary side of the exchangers were damaged; this lead to more rapid deterioration. The heat station's secondary side is an enclosed circuit for centralized heat supply, where the flowing water is not exchanged. That means that there is no water exchange as in the hot tap water preparation circuit. The damage resulted from the high sulphur content in this circuit.

A general recommendation in this case is to conduct a full chemical analysis of the water in the district heating circuit with specific attention to sulphur. If the presence of these compounds cannot be reduced, a fusion bonded heat exchanger consisting of 100% stainless steel such as the AlfaNova may be recommended. This would eliminate any further risk of copper corrosion. Fusion-bonded plate heat exchanger Alfa Nova is recommended after evaluation of assessment of plate heat exchangers in the conditions of the Czech Republic and specific case in one heating plant like best choice.

Zhua and Zhang (2003) recognized the cost of the plate heat exchangers can be more than 15% lower if the right method is used. Based on the information found, when selecting a plate exchanger, it is recommended to take care of the water quality to prevent similar situation from occurring again because the heat exchanger will be subject to the effects of water with a high sulphur content, which can damage the brazed joints, thus deteriorating the entire exchanger. If water quality will be sufficient, can be recommended cheaper copper brazed plate heat exchanger. For district heating side is copper brazed plate heat exchanger is recommended at all the times and for hot tap water is depend on the water quality.

# 7 Conclusion

This thesis contributes to the area of utilization of secondary heat in centralized heat supply systems in theoretical as well as practical aspects.

Chapter “Literature Overview” provides the basic information about heat exchangers. It introduces the theoretical calculation of recovery exchangers. The following theoretical part presents the design of plate heat exchangers, their important parts and shell-and tube heat exchangers.

Materials and methods are included in the practical part of the thesis. This chapter provides all input values used for subsequent calculations as well as explanation of the procedures selected to fulfil the objective of the thesis.

Chapter “Results” compiles data from the previous chapter and compares all the mentioned heat exchangers using the WSA method. Another part of this chapter is focused on specific copper brazed plate exchangers operated in practice, which were decommissioned after five years of operation for the reason of damage.

This is followed by chapter “Discussions”, which provides comments to all the results, specifying qualitatively the more efficient exchanger in each category. The technical analysis shows that the damage to the exchangers was not due to a design fault or incorrectly used materials. In these cases, the cause consisted in poor water quality; recommended solutions include using another type of exchanger or improving the quality of used water. In this chapter is recommendation for the best variant of this case of study.

As the conclusion to this thesis, can be say that plate exchangers are much more efficient than shell-and-tube heat exchangers, which were mostly used formerly. Plate exchangers offer lower maintenance costs and less cleaning, offering much higher energy efficiency. That is why their use limits the environmental impacts. It is also important to carefully select the plate exchanger for the specific application to avoid deterioration of the exchangers by the effects of adverse ambient conditions.

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## List of Figures

# List of Tables

# List of Attachment

**Attachment No. 1**

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# CB76 / CBH76

## Brazed Plate Heat Exchanger

### General information

Alfa Laval introduced its first brazed plate heat exchanger (BHE) in 1977 and has since continuously developed and optimized its performance and reliability.

Brazing the stainless steel plates together eliminates the need for gaskets and thick frame plates. The brazing material seals and holds the plates together at the contact points ensuring optimal heat transfer efficiency and pressure resistance. The plate design guarantees the longest possible life.

The design options of the brazed heat exchanger are extensive. Different plate patterns are available for various duties and performance specifications. You can choose a standard configuration BHE, or a unit designed according to your own specific needs. The choice is entirely yours.

### Typical applications

- HVAC heating/cooling
- Refrigerant applications
- Industrial heating/cooling
- Oil cooling

### Working principles

The heating surface consists of thin corrugated metal plates stacked on top of each other. Channels are formed between the plates and corner ports are arranged so that the two media flow through alternate channels, usually in counter-current flow for the most efficient heat transfer process.

### Standard design

The plate pack is covered by cover plates. Connections are located in the front or rear cover plate. To improve the heat transfer design, the channel plates are corrugated.

### Standard materials

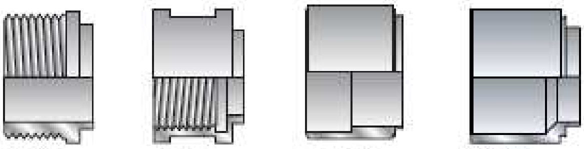
| | |
|---|---|
| Cover plates | Stainless steel |
| Connections | Stainless steel |
| Plates | Stainless steel |
| Brazing material | Copper |

### Particulars required for quotation

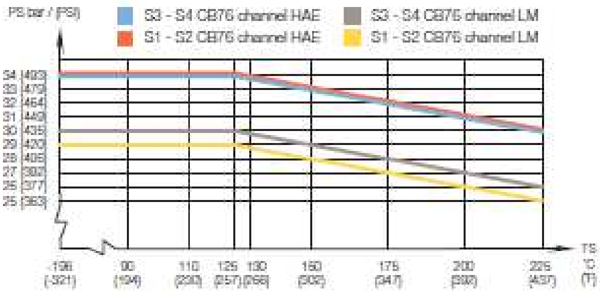
To enable Alfa Laval's representative to make a specific quotation, specify the following particulars in your enquiry:

- required flow rates or heat load
- temperature program
- physical properties of liquids in question
- desired working pressure
- maximum permitted pressure drop

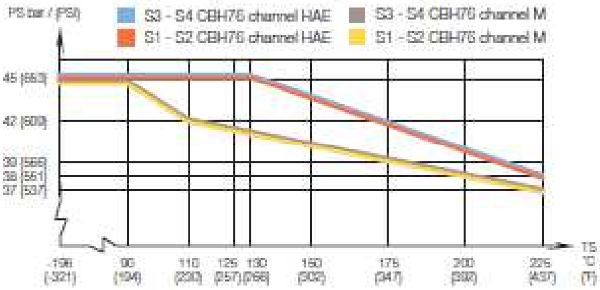
### Examples of connections



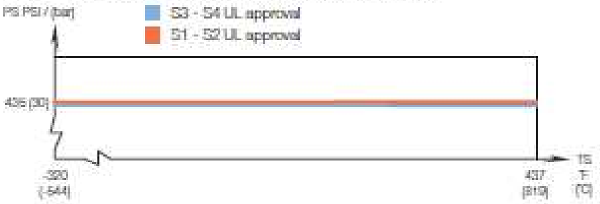
CB76 – PED approval pressure/temperature graph*



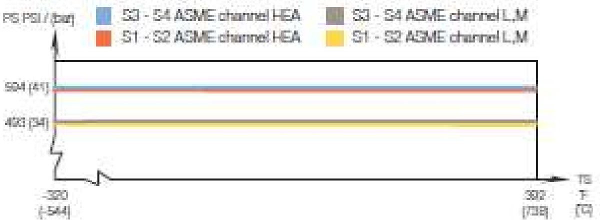

CBH76 – PED approval pressure/temperature graph*



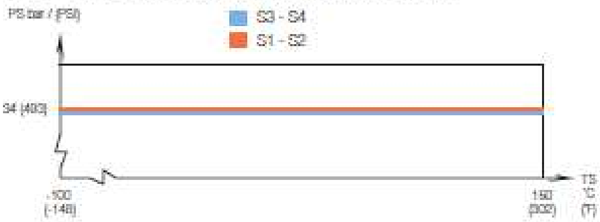

CB76 - UL approval pressure/temperature graph*




CB76 - ASME approval pressure/temperature graph*




CB76 – KHK approval pressure/temperature graph*




* For exact values please contact your local Alfa Laval representative.

## Standard data

| | |
|---|---|
| Min. working temperature | see graph |
| Max. working temperature | see graph |
| Min. working pressure | Vacuum |
| Max. working pressure | see graph |
| Volume per channel, litres (ga) | 0.18 - 0.25 (0.05 - 0.07) |
| Max particle size mm (inch) | 1.2 (0.05) |
| Max flowrate m³/h (gpm)* | 37 (163) |
| Min no of plates | 10 |
| Max no of plates | 190 |

* Water at 5 m/s (16.4 ft/s) (connection velocity)

## Standard dimension and weight*

### CB76

A channel — A measure mm = 10 + (n x 2.5) ± 5
A measure inch = 0.39 + (n x 0.098) ± 0.19

E channel — A measure mm = 10 + (n x 2.2) ± 5
A measure inch = 0.39 + (n x 0.09) ± 0.19

H, L, M channels — A measure mm = 10 + (n x 2.85) ± 5
A measure inch = 0.39 + (n x 0.09) ± 0.19

Weight** kg = 8 + (n x 0.44)
Weight** lb = 17.6 + (n x 0.97)

### CBH76

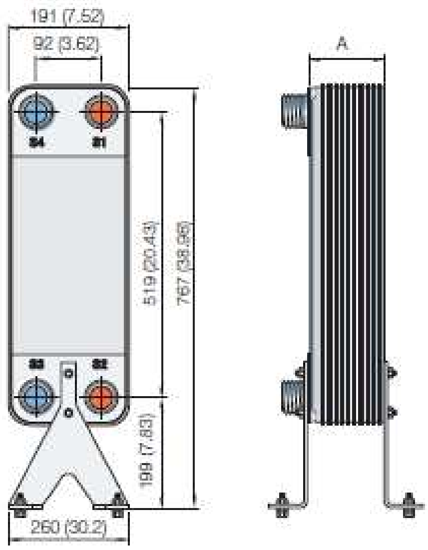
A channel — A measure mm = 14 + (n x 2.5) ± 5
A measure inch = 0.55 + (n x 0.098) ± 0.19

E channel — A measure mm = 14 + (n x 2.2) ± 5
A measure inch = 0.55 + (n x 0.09) ± 0.19

H, M channels — A measure mm = 14 + (n x 2.85) ± 5
A measure inch = 0.39 + (n x 0.11) ± 0.19

Weight** kg = 10 + (n x 0.44)
Weight** lb = 22 + (n x 0.97)

** excluding connections
(n = number of plates)




**Source – Alfa Laval, s.r.o.**

**Attachment No. 2**

# CB200 / CBH200

## Brazed Plate Heat Exchanger

### General information

Alfa Laval introduced its first brazed plate heat exchanger (BHE) in 1977 and has since continuously developed and optimized its performance and reliability.

Brazing the stainless steel plates together eliminates the need for gaskets and thick frame plates. The brazing material seals and holds the plates together at the contact points ensuring optimal heat transfer efficiency and pressure resistance. The plate design guarantees the longest possible life.

The design options of the brazed heat exchanger are extensive. Different plate patterns are available for various duties and performance specifications. You can choose a standard configuration BHE, or a unit designed according to your own specific needs. The choice is entirely yours.

### Typical applications

Liquid/liquid applications:
- HVAC heating/cooling
- Process heating/cooling
- Hydraulic oil cooling
- Oil cooling

### Working principles

The heating surface consists of thin corrugated metal plates stacked on top of each other. Channels are formed between the plates and corner ports are arranged so that the two media flow through alternate channels, usually in countercurrent flow for the most efficient heat transfer process.

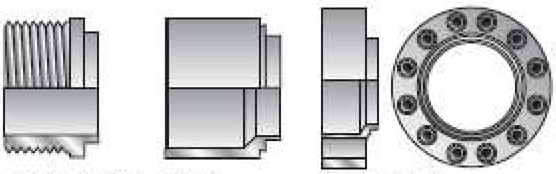
### Standard design

The plate pack is covered by cover plates. Connections are located in the front or rear cover plate. To improve the heat transfer design, the channel plates are corrugated.

### Particulars required for quotation

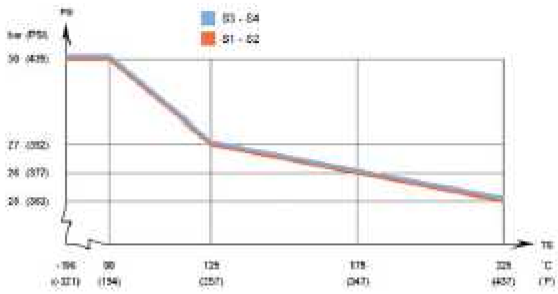
To enable Alfa Laval's representative to make a specific quotation, specify the following particulars in your enquiry:
- Required flow rates or heat load
- Temperature program
- Physical properties of liquids in question
- Desired working pressure
- Maximum permitted pressure drop

### Examples of connections

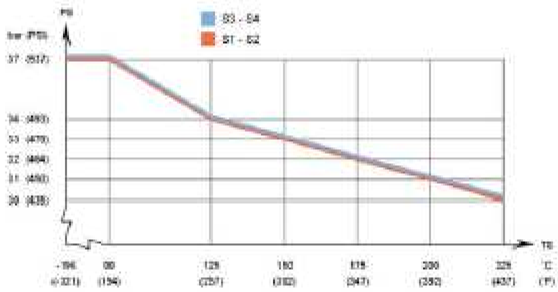


External threaded    Welding    Compact flanges

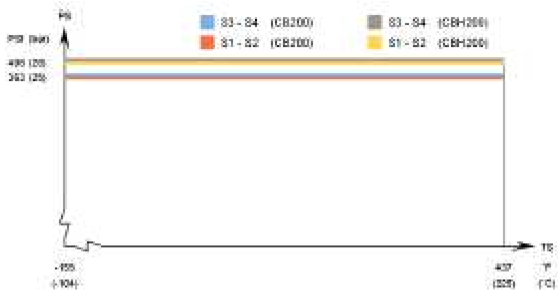
CB200 - PED approval pressure/temperature graph*



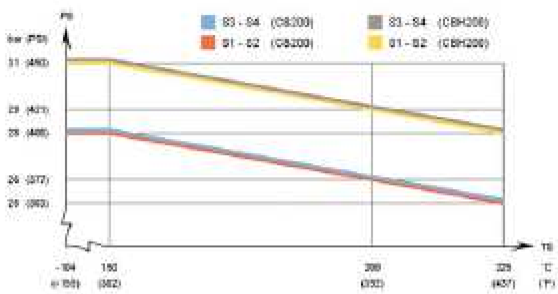
CBH200 - PED approval pressure/temperature graph*



CB200 / CBH200 - ASME approval pressure/temperature graph*



CB200 / CBH200 - CRN approval pressure/temperature graph*



## Standard dimensions and weight*

**CB200**

A measure mm = 11 + (2.7 * n) (+/-10 mm)
A measure inch = 0.43 + (0.11 * n) (+/-0.39 inch)
Weight** kg = 12 + (0.6 * n)
Weight** lb = 26.46 + (1.32 * n)

**CBH200**

A measure mm = 14 + (2.7 * n) (+/-10 mm)
A measure inch = 0.55 + (0.11 * n) (+/-0.39 inch)
Weight** kg = 14 + (0.6 * n)
Weight** lb = 30.86 + (1.32 * n)

(n = number of plates)
* Excluding connections

## Standard data

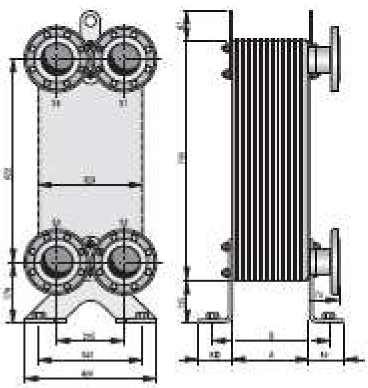
| | |
|---|---|
| Min. working temperature | see graph |
| Max. working temperature | see graph |
| Min. working pressure | vacuum |
| Max. working pressure | see graph |
| Volume per channel, litres (ga) | 0.51 (0.13) |
| Max. particle size mm (inch) | 1.8 (0.07) |
| Max. flowrate* m³/h (gpm) | 128 (561) |
| Min. nbr of plates | 10 |
| Max. nbr of plates | 230 |

* Water at 5 m/s (16.4 ft/s) (connection velocity)

## Standard materials

| | |
|---|---|
| Cover plates | Stainless steel |
| Connections | Stainless steel |
| Plates | Stainless steel |
| Brazing material | Copper |

## Standard dimensions
mm (inch)



## Marine approvals
CBMH200 can be delivered with marine classification certificate (ABS, BV, CCS, Class NK, DNV, GL, LR, RINA, RMRS).

For exact values please contact your local Alfa Laval representative

**Source – Alfa Laval, s.r.o.**

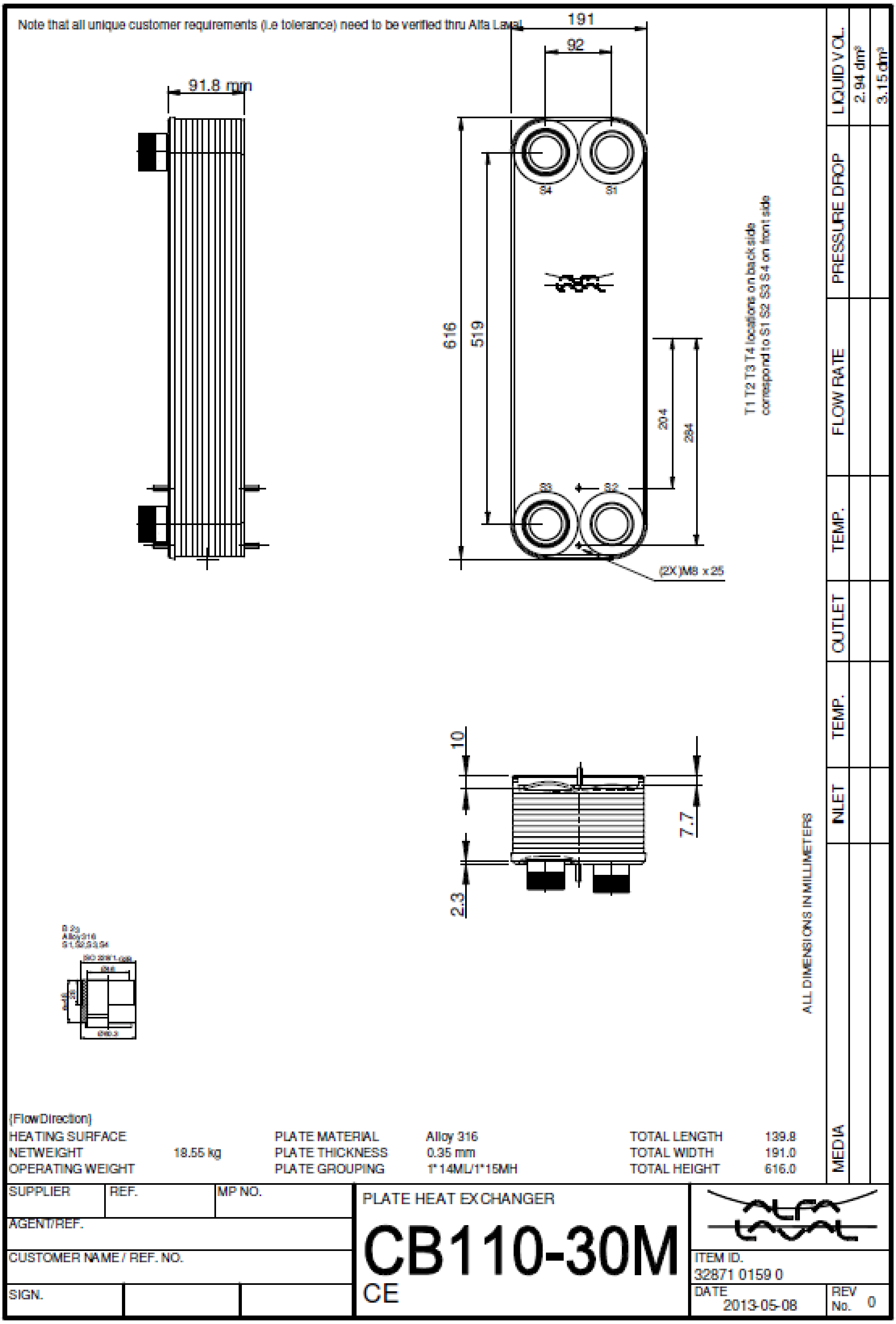
**Attachment No. 3**

# Brazed Plate Heat Exchanger

**Technical Specification**

| | | | |
|---|---|---|---|
| Mode | : CB110-30M (32871 0159 0) | | |
| Project | : Michal DT | Units | : 1 |
| ItemName | : CB110-30M 32871 0159 0 | Date | : 27.1.2015 |

| | | Hot Side S4S3 | Cold Side S2S1 |
|---|---|---|---|
| Fluid | | Water | Water |
| Density | kg/m3 | 973.1 | 980.1 |
| Specific heat capacity | kJ/(kg*K) | 4.18 | 4.18 |
| Thermal conductivity | W/(m*K) | 0.667 | 0.657 |
| Viscosity inlet | cP | 0.214 | 0.465 |
| Viscosity outlet | cP | 0.442 | 0.353 |
| Volume flow rate | m3/h | 3.4 | 11.0 |
| Inlet temperature | °C | 130.0 | 60.0 |
| Outlet temperature | °C | 63.4 | 80.0 |
| Pressure drop | kPa | 2.07 | 18.2 |
| Heat exchanged | kW | 250.0 | |
| L.M.T.D. | K | 17.3 | |
| OHTC clean conditions | W/(m2*K) | 4615 | |
| OHTC service | W/(m2*K) | 4616 | |
| Heat transfer area | m2 | 3.14 | |
| Fouling resistance*10000 | m2*K/W | 0.000 | |
| Duty margin | % | 0.00 | |
| Relative direction of the fluids | | Countercurrent | |
| Number of passes | | 1 | 1 |
| Materialplate/ brazing | | Alloy 316 / Cu | |
| ConnectionS1 (Cold-out) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS2 (Cold-in) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS3 (Hot-out) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS4 (Hot-in) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| Pressure vessel code | | PED | |
| Design pressure at 90.000 Celsius | Bar | 30.00 | 30.00 |
| Design pressure at 225.00 Celsius | Bar | 25.00 | 25.00 |
| Design temperature | °C | -196.0/225.0 | |
| Overall length x width x height | mm | 140 x 191 x 616 | |
| Net weight, empty / operating | kg | 19.4 / 25.3 | |
| Package length x width x height | mm | 150 x 210 x 700 | |
| Package weight | kg | 2.425 | |




**Source – Alfa Laval, s.r.o.**

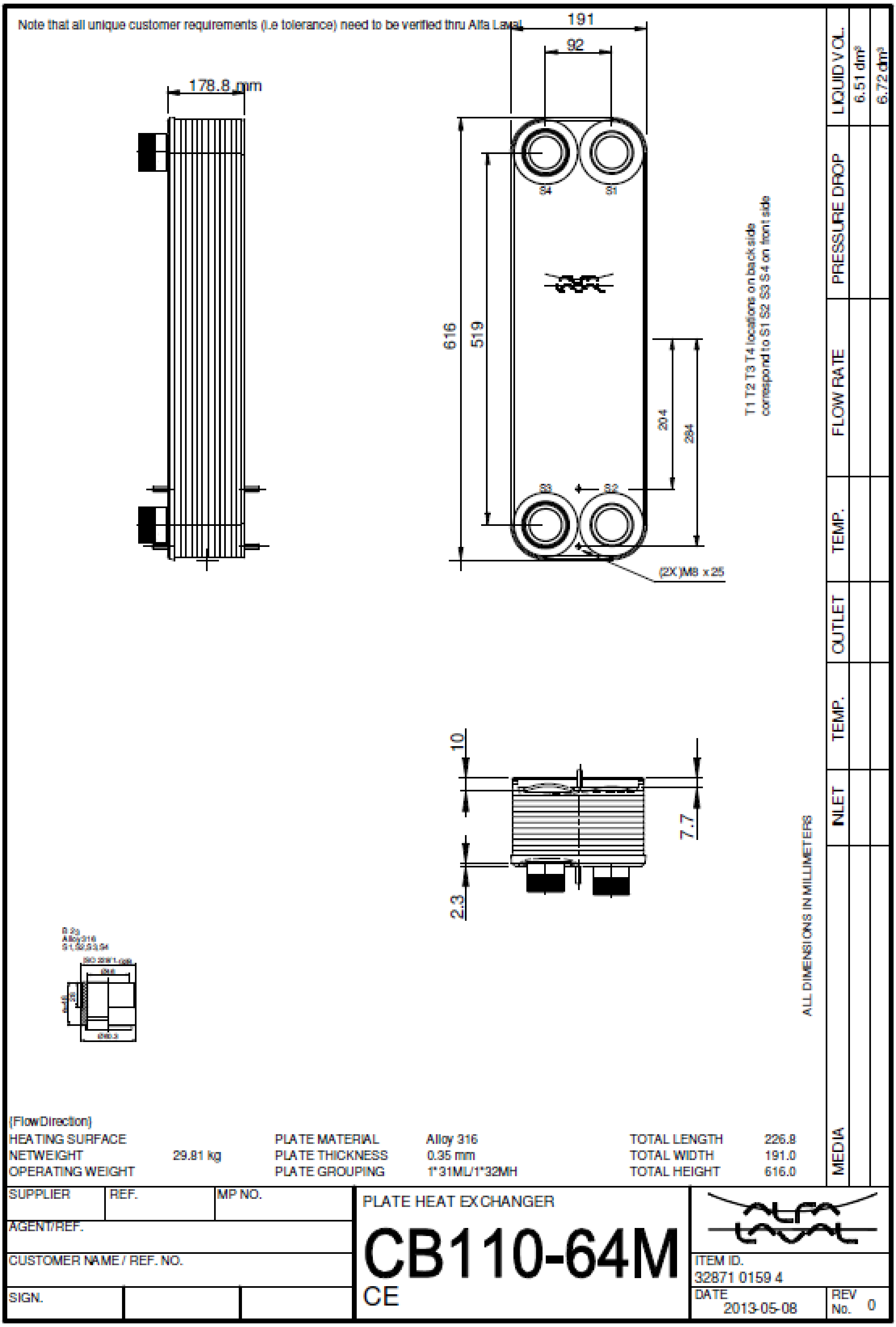
**Attachment No. 4**

# Brazed Plate Heat Exchanger

**Technical Specification**

| | | | |
|---|---|---|---|
| Model | : CB110-64M (32871 0159 4) | | |
| Project | : Michal DT | Units | : 1 |
| ItemName | : CB110-64M 32871 0159 4 | Date | : 27.1.2015 |

| | | **Hot Side S4S3** | **Cold side S2S1** |
|---|---|---|---|
| Fluid | | Water | Water |
| Density | kg/m3 | 973.9 | 980.3 |
| Specific heat capacity | kJ/(kg*K) | 4.18 | 4.18 |
| Thermal conductivity | W/(m*K) | 0.666 | 0.656 |
| Viscosity inlet | cP | 0.214 | 0.465 |
| Viscosity outlet | cP | 0.446 | 0.353 |
| Volume flow rate | m3/h | 6.8 | 21.9 |
| Inlet temperature | °C | 130.0 | 60.0 |
| Outlet temperature | °C | 62.8 | 80.0 |
| Pressure drop | kPa | 2.04 | 20.2 |
| Heat exchanged | kW | 500.0 | |
| L.M.T.D. | K | 16.5 | |
| OHTC clean conditions | W/(m2*K) | 4373 | |
| OHTC service | W/(m2*K) | 4373 | |
| Heat transfer area | m2 | 6.94 | |
| Fouling resistance*10000 | m2*K/W | 0.000 | |
| Duty margin | % | 0.00 | |
| Relative directions of fluids | | Countercurrent | |
| Number of passes | | 1 | 1 |
| Materialplate/ brazing | | Alloy 316 / Cu | |
| ConnectionS1 (Cold-out) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS2 (Cold-in) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS3 (Hot-out) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS4 (Hot-in) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| Pressure vessel code | | PED | |
| Design pressure at 90.000 Celsius | Bar | 30.00 | 30.00 |
| Design pressure at 225.00 Celsius | Bar | 25.00 | 25.00 |
| Design temperature | °C | -196.0/225.0 | |
| Overall length x width x height | mm | 227 x 191 x 616 | |
| Net weight, empty / operating | kg | 31.5 / 44.3 | |
| Package length x width x height | mm | 365 x 210 x 700 | |
| Package weight | kg | 2.695 | |




**Source – Alfa Laval, s.r.o.**

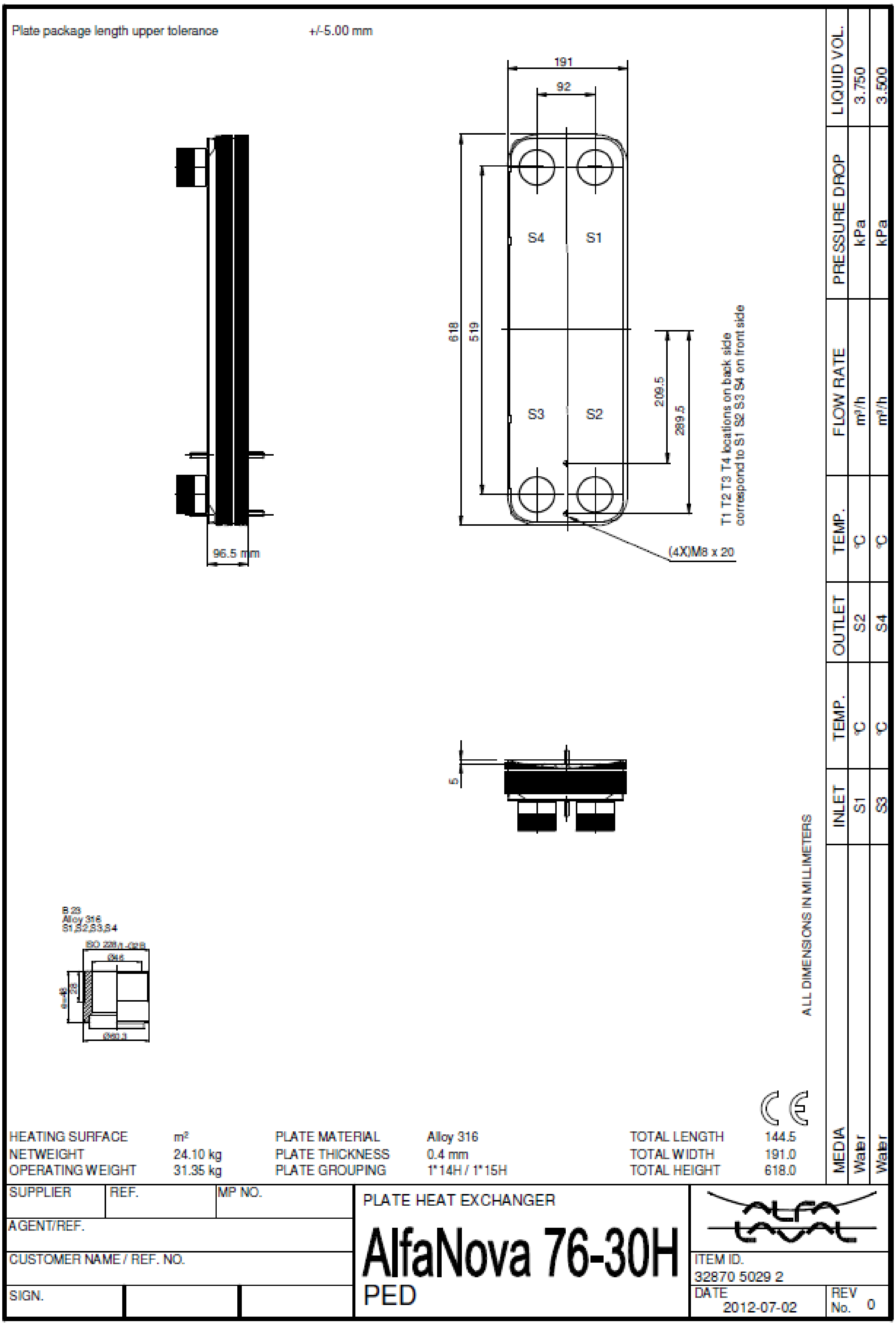
**Attachment No. 5**

# AlfaNovaPlate Heat Exchanger

**Technical Specification**

| | | | |
|---|---|---|---|
| Mode | : AlfaNova 76-30H (32870 5029 2) | | |
| Project | : Michal DT | Units | : 1 |
| ItemName | : AlfaNova 76-30H 32870 5029 2 | Date | : 27.1.2015 |

| | | **Hot Side S4S3** | **Cold Side S2S1** |
|---|---|---|---|
| Fluid | | Water | Water |
| Density | kg/m3 | 987.9 | 994.7 |
| Specific heat capacity | kJ/(kg*K) | 4.17 | 4.18 |
| Thermal conductivity | W/(m*K) | 0.639 | 0.616 |
| Viscosity inlet | cP | 0.353 | 1.31 |
| Viscosity outlet | cP | 0.931 | 0.503 |
| Volume flow rate | m3/h | 3.9 | 4.8 |
| Inlet temperature | °C | 80.0 | 10.0 |
| Outlet temperature | °C | 23.3 | 55.0 |
| Pressure drop | kPa | 8.16 | 11.3 |
| Heat exchanged | kW | 250.0 | |
| L.M.T.D | K | 18.5 | |
| OHTC clean conditions | W/(m2*K) | 4808 | |
| OHTC service | W/(m2*K) | 4808 | |
| Heat transfer area | m2 | 2.80 | |
| Fouling resistance*10000 | m2*K/W | 0.000 | |
| Duty margin | % | 0.00 | |
| Relative direction of the fluids | | Countercurrent | |
| Number of passes | | 1 | 1 |
| Materialplate/ brazing | | Alloy 316 / Cu | |
| ConnectionS1 (Cold-out) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS2 (Cold-in) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS3 (Hot-out) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS4 (Hot-in) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| Pressure vessel code | | PED | |
| Design pressure at 75.000 Celsius | Bar | 30.00 | 30.00 |
| Design pressure at 225.00 Celsius | Bar | 26.00 | 26.00 |
| Design temperature | °C | -196.0/225.0 | |
| Overall length x width x height | mm | 145 x 191 x 618 | |
| Net weight, empty / operating | kg | 23.8 / 31.0 | |
| Package length x width x height | mm | 150 x 210 x 700 | |
| Package weight | kg | 2.425 | |




**Source – Alfa Laval, s.r.o.**

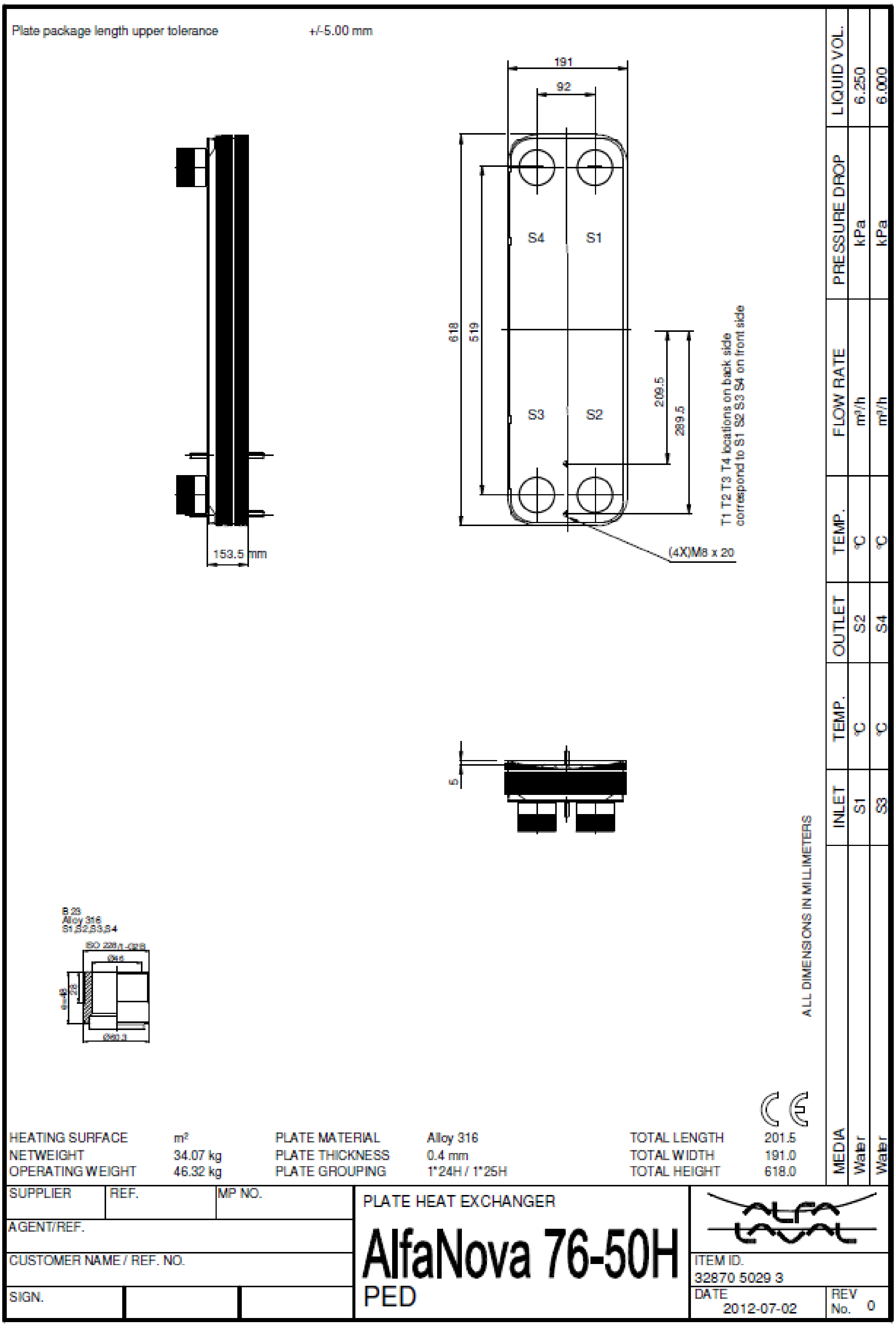
**Attachment No. 6**

# AlfaNovaPlate Heat Exchanger

**Technical Specification**

| | | | | |
|---|---|---|---|---|
| Mode | : AlfaNova 76-50H (32870 5029 3) | | | |
| Project | : Michal DT | | Units | : 1 |
| ItemName | : AlfaNova 76-50H 32870 5029 3 | | Date | : 27.1.2015 |

| | | **Hot Side** | **Cold Side** |
|---|---|---|---|
| | | **S4S3** | **S2S1** |
| Fluid | | Water | Water |
| Density | kg/m3 | 987.4 | 994.6 |
| Specific heat capacity | kJ/(kg*K) | 4.17 | 4.18 |
| Thermal conductivity | W/(m*K) | 0.641 | 0.617 |
| Viscosity inlet | cP | 0.353 | 1.31 |
| Viscosity outlet | cP | 0.903 | 0.503 |
| Volume flow rate | m3/h | 8.0 | 9.6 |
| Inlet temperature | °C | 80.0 | 10.0 |
| Outlet temperature | °C | 24.6 | 55.0 |
| Pressure drop | kPa | 11.9 | 16.7 |
| Heat exchanged | kW | 500.0 | |
| L.M.T.D | K | 19.3 | |
| OHTC clean conditions | W/(m2*K) | 5402 | |
| OHTC service | W/(m2*K) | 5402 | |
| Heat transfer area | m2 | 4.80 | |
| Fouling resistance*10000 | m2*K/W | 0.000 | |
| Duty margin | % | 0.00 | |
| Relative direction of the fluids | | Countercurrent | |
| Number of passes | | 1 | 1 |
| Materialplate/ brazing | | Alloy 316 / Cu | |
| ConnectionS1 (Cold-out) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS2 (Cold-in) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS3 (Hot-out) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| ConnectionS4 (Hot-in) | | Threaded (External)/ 2" ISO 228/1-G (B23) Alloy 316 | |
| Pressure vessel code | | PED | |
| Design pressure at 75.000 Celsius | Bar | 30.00 | 30.00 |
| Design pressure at 225.00 Celsius | Bar | 26.00 | 26.00 |
| Design temperature | °C | -196.0/225.0 | |
| Overall length x width x height | mm | 201 x 191 x 618 | |
| Net weight, empty / operating | kg | 33.8 / 45.9 | |
| Package length x width x height | mm | 355 x 210 x 700 | |
| Package weight | kg | 2.695 | |




**Source – Alfa Laval, s.r.o.**

**Attachment No. 7**

# SECESPOL - VÝPOČTOVÝ LIST VÝMĚNÍKU TEPLA

| | |
|---|---|
| Nabídka | |
| Číslo výpočtu | |
| Vypracoval/Datum | 05.03.2015 |
| **Typ výměníku tepla** | **JAD X 5.38 MF.STA.CS** |
| **Katalogové číslo** | **0126-0113** |
| Celkový počet výměníků | 1 |
| Počet ks sériově/paralelně | 1/1 |

## NÁVRHOVÉ HODNOTY:

| | Strana 1 - Trubky | | Strana 2 - Plášť | |
|---|---|---|---|---|
| Výkon | | 250,0 | | kW |
| LMTD | | 19,5 | | °C |
| Min. rezerva | | 0 | | % |
| Médium | Water | | Water | |
| Vstupní teplota | 130,0 | | 60,0 | °C |
| Výstupní teplota | 65,0 | | 80,0 | °C |
| Hmotnostní průtok | 0,92 | | 2,99 | kg/s |
| Objemový průtok vstup | 3,53 | | 10,91 | $m^3/h$ |
| Objemový průtok výstup | 3,36 | | 11,04 | $m^3/h$ |
| Max. tlaková ztráta | 20,0 | | 20,0 | kPa |
| Návrhový tlak | 2,5 | | 1,6 | MPa |
| Návrhová teplota | 130 | | 80 | °C |

## VYBRANÝ VÝMĚNÍK TEPLA:

(Standardní výpočet)

| | Strana 1 - Trubky | | Strana 2 - Plášť | |
|---|---|---|---|---|
| Teplosměnná plocha | | 4,0 | | $m^2$ |
| Faktor znečištění | | 0,0137 | | $m^2K/kW$ |
| k čistý | | 3326,9 | | $W/m^2K$ |
| k znečištěný | | 3182,1 | | $W/m^2K$ |
| Rezerva | | 5 | | % |
| Vypočt. tlak. ztráta | 11,5 | | 12,7 | kPa |
| Tlaková ztráta na hrdle | 0,0 | | 0,3 | kPa |
| Rychlost na hrdle | 0,25 | | 0,79 | m/s |
| Vnitřní rychlost | 0,67 | | 0,95 | m/s |
| Reynoldsovo číslo | 15418 | | 6825 | - |
| Koefic. přest. tep. | 6229,7 | | 9754,3 | $W/m^2K$ |

## FYZIKÁLNÍ VLASTNOSTI:

| | Strana 1 - Trubky | Strana 2 - Plášť | |
|---|---|---|---|
| Médium | Water | Water | |
| Ref. teplota | 97,5 | 70,0 | °C |
| Hustota | 960,78 | 979,82 | $kg/m^3$ |
| Tepelný obsah | 4,19 | 4,19 | kJ/kgK |
| Tepelná vodivost | 0,676 | 0,653 | W/mK |
| Dyn. viskosita | 0,0003 | 0,0004 | $Ns/m^2$ |
| Prandtlovo číslo | 1,80 | 2,63 | - |

# SECESPOL - TECHNIKÝ LIST VÝMĚNÍKU TEPLA

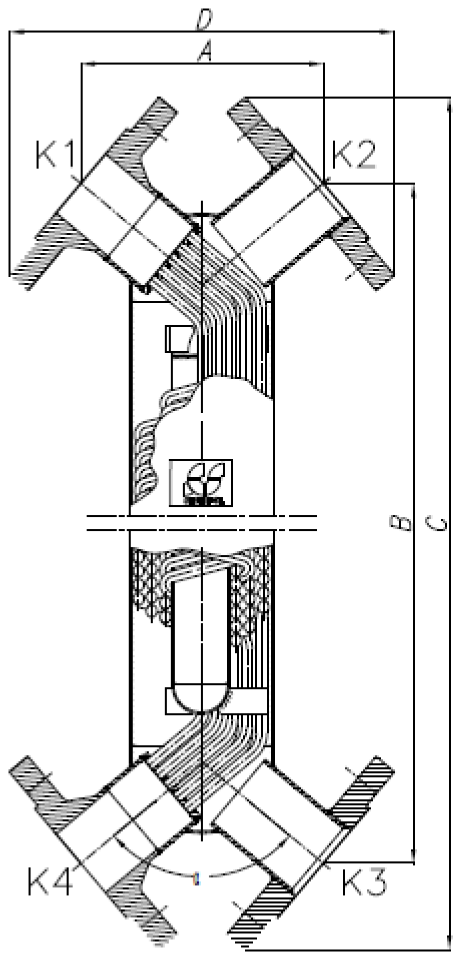
**Typ výměníku tepla** **JAD X 5.38 MF.STA.CS**
**Katalogové číslo** **0126-0113**

## PRACOVNÍ PARAMETRY:

| | Strana trubek | Strana pláště | |
|---|---|---|---|
| Maximální tlak | 25 | 16 | bar |
| Maximální teplota | 250 | 203 | °C |
| Minimální teplota | 0 | 0 | °C |
| Skupina média | 2 | 2 | |

## KONSTRUKČNÍ PARAMETRY:

| | | |
|---|---|---|
| Typ teplosměnné plochy | Hladká trubka 8,0 mm | |
| Teplosměnná plocha | 4,0 | m² |
| Objem trubkovnice | 6,6 | l |
| Objem pláště | 11,2 | l |
| Hmotnost | 41,7 | kg |
| SKUPINA MATERIÁLŮ: | SS 18-10 | |




## STANDARDNÍ ZAPOJENÍ:
**(protiproud)**

K1 - vstup topného média
K2 - výstup ohřívaného média
K3 - vstup ohřívaného média
K4 - výstup topného média

## ROZMĚRY:

| | | |
|---|---|---|
| A | 201,0 | mm |
| B | 1510,0 | mm |
| C | 1649,0 | mm |
| D | 317,0 | mm |
| Dz | 140,0 | mm |
| alfa | 100,0 | mm |

## TYPY PŘIPOJENÍ:

K1 - Krková příruba CS DN65 PN40 TYP 11B
K2 - Plochá příruba CS DN65 PN16 TYP 01B
K3 - Plochá příruba CS DN65 PN16 TYP 01B
K4 - Krková příruba CS DN65 PN40 TYP 11B

**Source – Secespol – CZ, s.r.o.**

**Attachment No. 8**

# SECESPOL - VÝPOČTOVÝ LIST VÝMĚNÍKU TEPLA

| | |
|---|---|
| Nabídka | |
| Číslo výpočtu | |
| Vypracoval/Datum | 05.03.2015 |
| **Typ výměníku tepla** | **JAD X 9.88 MF.STA.CS** |
| **Katalogové číslo** | **0128-0001** |
| Celkový počet výměníků | 1 |
| Počet ks sériově/paralelně | 1/1 |

## NÁVRHOVÉ HODNOTY:

| | **Strana 1 - Trubky** | | **Strana 2 - Plášť** | |
|---|---|---|---|---|
| Výkon | | 500,0 | | kW |
| LMTD | | 19,5 | | °C |
| Min. rezerva | | 0 | | % |
| Médium | Water | | Water | |
| Vstupní teplota | 130,0 | | 60,0 | °C |
| Výstupní teplota | 65,0 | | 80,0 | °C |
| Hmotnostní průtok | 1,83 | | 5,97 | kg/s |
| Objemový průtok vstup | 7,07 | | 21,82 | m³/h |
| Objemový průtok výstup | 6,72 | | 22,09 | m³/h |
| Max. tlaková ztráta | 20,0 | | 20,0 | kPa |
| Návrhový tlak | 2,5 | | 1,6 | MPa |
| Návrhová teplota | 130 | | 80 | °C |

## VYBRANÝ VÝMĚNÍK TEPLA:

(Standardní výpočet)

| | **Strana 1 - Trubky** | | **Strana 2 - Plášť** | |
|---|---|---|---|---|
| Teplosměnná plocha | | 10,7 | | m² |
| Faktor znečištění | | 0,0304 | | m²K/kW |
| k čistý | | 2578,6 | | W/m²K |
| k znečištěný | | 2391,1 | | W/m²K |
| Rezerva | | 8 | | % |
| Vypočt. tlak. ztráta | 5,4 | | 6,8 | kPa |
| Tlaková ztráta na hrdle | 0,0 | | 0,2 | kPa |
| Rychlost na hrdle | 0,21 | | 0,66 | m/s |
| Vnitřní rychlost | 0,58 | | 0,76 | m/s |
| Reynoldsovo číslo | 13242 | | 5437 | - |
| Koefic. přest. tep. | 4755,7 | | 7143,0 | W/m²K |

## FYZIKÁLNÍ VLASTNOSTI:

| | **Strana 1 - Trubky** | **Strana 2 - Plášť** | |
|---|---|---|---|
| Médium | Water | Water | |
| Ref. teplota | 97,5 | 70,0 | °C |
| Hustota | 960,78 | 979,82 | kg/m³ |
| Tepelný obsah | 4,19 | 4,19 | kJ/kgK |
| Tepelná vodivost | 0,676 | 0,653 | W/mK |
| Dyn. viskosita | 0,0003 | 0,0004 | Ns/m² |
| Prandtlovo číslo | 1,80 | 2,63 | - |

# SECESPOL - TECHNIKÝ LIST VÝMĚNÍKU TEPLA

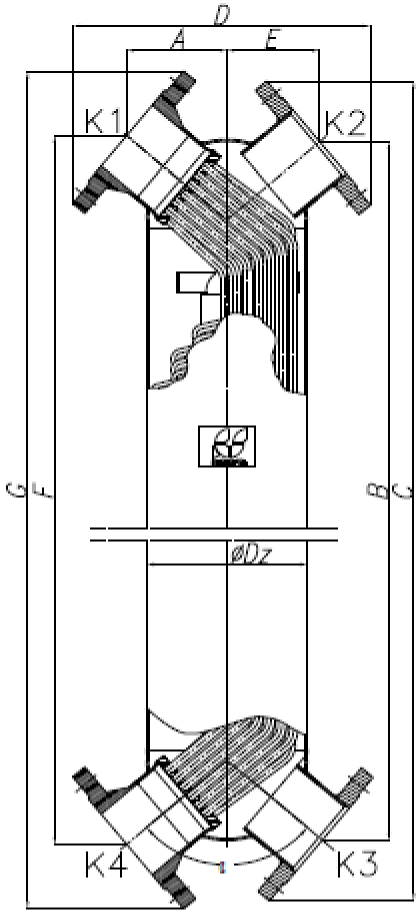
| | |
|---|---|
| **Typ výměníku tepla** | **JAD X 9.88 MF.STA.CS** |
| **Katalogové číslo** | **0128-0001** |

## PRACOVNÍ PARAMETRY:

| | **Strana trubek** | **Strana pláště** | |
|---|---|---|---|
| Maximální tlak | 25 | 16 | bar |
| Maximální teplota | 250 | 203 | °C |
| Minimální teplota | 0 | 0 | °C |
| Skupina média | 2 | 2 | |

## KONSTRUKČNÍ PARAMETRY:

| | | |
|---|---|---|
| Typ teplosměnné plochy | Hladká trubka 8,0 mm | |
| Teplosměnná plocha | 10,7 | m² |
| Objem trubkovnice | 16,0 | l |
| Objem pláště | 29,0 | l |
| Hmotnost | 98,0 | kg |
| SKUPINA MATERIÁLŮ: | SS 18-10 | |




## STANDARDNÍ ZAPOJENÍ:
**(protiproud)**

K1 - vstup topného média
K2 - výstup ohřívaného média
K3 - vstup ohřívaného média
K4 - výstup topného média

## ROZMĚRY:

| | | |
|---|---|---|
| A | 137,0 | mm |
| B | 1481,0 | mm |
| C | 1645,0 | mm |
| D | 412,0 | mm |
| Dz | 219,0 | mm |
| E | 126,0 | mm |

## TYPY PŘIPOJENÍ:

K1 - Krková příruba CS DN100 PN40 TYP 11B
K2 - Plochá příruba CS DN100 PN16 TYP 01B
K3 - Plochá příruba CS DN100 PN16 TYP 01B
K4 - Krková příruba CS DN100 PN40 TYP 11B

**Source – Secespol – CZ, s.r.o.**

**Attachment No. 9**

# SECESPOL - VÝPOČTOVÝ LIST VÝMĚNÍKU TEPLA

| | |
|---|---|
| Nabídka | |
| Číslo výpočtu | |
| Vypracoval/Datum | 05.03.2015 |
| **Typ výměníku tepla** | **JAD X 12.114 MF.STA.CS** |
| **Katalogové číslo** | **0130-0001** |
| Celkový počet výměníků | 1 |
| Počet ks sériově/paralelně | 1/1 |

## NÁVRHOVÉ HODNOTY:

| | Strana 1 - Trubky | | Strana 2 - Plášť | |
|---|---|---|---|---|
| Výkon | | 250,0 | | kW |
| LMTD | | 19,9 | | °C |
| Min. rezerva | | 0 | | % |
| Médium | Water | | Water | |
| Vstupní teplota | 80,0 | | 10,0 | °C |
| Výstupní teplota | 25,5 | | 55,0 | °C |
| Hmotnostní průtok | 1,10 | | 1,33 | kg/s |
| Objemový průtok vstup | 4,05 | | 4,78 | m³/h |
| Objemový průtok výstup | 3,95 | | 4,83 | m³/h |
| Max. tlaková ztráta | 20,0 | | 20,0 | kPa |
| Návrhový tlak | 2,5 | | 1,6 | MPa |
| Návrhová teplota | 80 | | 55 | °C |

## VYBRANÝ VÝMĚNÍK TEPLA:

(Standardní výpočet)

| | Strana 1 - Trubky | | Strana 2 - Plášť | |
|---|---|---|---|---|
| Teplosměnná plocha | | 18,4 | | m² |
| Faktor znečištění | | 0,0069 | | m²K/kW |
| k čistý | | 686,9 | | W/m²K |
| k znečištěný | | 683,7 | | W/m²K |
| Rezerva | | 0 | | % |
| Vypočt. tlak. ztráta | 2,0 | | 0,3 | kPa |
| Tlaková ztráta na hrdle | 0,0 | | 0,0 | kPa |
| Rychlost na hrdle | 0,08 | | 0,09 | m/s |
| Vnitřní rychlost | 0,26 | | 0,11 | m/s |
| Reynoldsovo číslo | 3371 | | 425 | - |
| Koefic. přest. tep. | 1542,1 | | 1299,2 | W/m²K |

## FYZIKÁLNÍ VLASTNOSTI:

| | Strana 1 - Trubky | Strana 2 - Plášť | |
|---|---|---|---|
| Médium | Water | Water | |
| Ref. teplota | 52,8 | 32,5 | °C |
| Hustota | 989,23 | 996,66 | kg/m³ |
| Tepelný obsah | 4,19 | 4,19 | kJ/kgK |
| Tepelná vodivost | 0,635 | 0,610 | W/mK |
| Dyn. viskosita | 0,0005 | 0,0008 | Ns/m² |
| Prandtlovo číslo | 3,48 | 5,20 | - |

# SECESPOL - TECHNIKÝ LIST VÝMĚNÍKU TEPLA

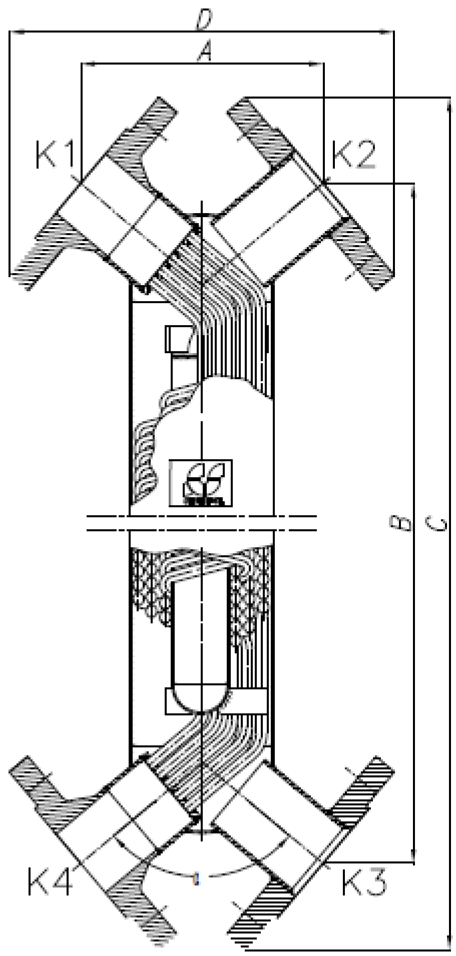
**Typ výměníku tepla** **JAD X 12.114 MF.STA.CS**
**Katalogové číslo** **0130-0001**

## PRACOVNÍ PARAMETRY:

| | Strana trubek | Strana pláště | |
|---|---|---|---|
| Maximální tlak | 25 | 16 | bar |
| Maximální teplota | 250 | 203 | °C |
| Minimální teplota | 0 | 0 | °C |
| Skupina média | 2 | 2 | |

## KONSTRUKČNÍ PARAMETRY:

| | | |
|---|---|---|
| Typ teplosměnné plochy | Hladká trubka 8,0 mm | |
| Teplosměnná plocha | 18,4 | m² |
| Objem trubkovnice | 20,1 | l |
| Objem pláště | 54,2 | l |
| Hmotnost | 156,0 | kg |
| SKUPINA MATERIÁLŮ: | SS 18-10 | |




## STANDARDNÍ ZAPOJENÍ:
**(protiproud)**

K1 - vstup topného média
K2 - výstup ohřívaného média
K3 - vstup ohřívaného média
K4 - výstup topného média

## ROZMĚRY:

| | | |
|---|---|---|
| A | 344,0 | mm |
| B | 1681,0 | mm |
| C | 1883,0 | mm |
| D | 484,0 | mm |
| Dz | 273,0 | mm |
| alfa | 110,0 | mm |

## TYPY PŘIPOJENÍ:

K1 - Krková příruba CS DN125 PN40 TYP 11B
K2 - Plochá příruba CS DN125 PN16 TYP 01B
K3 - Plochá příruba CS DN125 PN16 TYP 01B
K4 - Krková příruba CS DN125 PN40 TYP 11B

**Source – Secespol – CZ, s.r.o.**

**Attachment No. 10**

# SECESPOL - VÝPOČTOVÝ LIST VÝMĚNÍKU TEPLA

Nabídka
Číslo výpočtu
Vypracoval/Datum 05.03.2015

| | |
|---|---|
| **Typ výměníku tepla** | **JAD X 12.114 MF.STA.CS** |
| **Katalogové číslo** | **0130-0001** |
| Celkový počet výměníků | 1 |
| Počet ks sériově/paralelně | 1/1 |

## NÁVRHOVÉ HODNOTY:

| | Strana 1 - Trubky | | Strana 2 - Plášť | |
|---|---|---|---|---|
| Výkon | | 500,0 | | kW |
| LMTD | | 22,4 | | °C |
| Min. rezerva | | 0 | | % |
| Médium | Water | | Water | |
| Vstupní teplota | 80,0 | | 10,0 | °C |
| Výstupní teplota | 30,0 | | 55,0 | °C |
| Hmotnostní průtok | 2,39 | | 2,65 | kg/s |
| Objemový průtok vstup | 8,84 | | 9,56 | m³/h |
| Objemový průtok výstup | 8,63 | | 9,66 | m³/h |
| Max. tlaková ztráta | 20,0 | | 20,0 | kPa |
| Návrhový tlak | 2,5 | | 1,6 | MPa |
| Návrhová teplota | 80 | | 55 | °C |

## VYBRANÝ VÝMĚNÍK TEPLA:

(Standardní výpočet)

| | Strana 1 - Trubky | | Strana 2 - Plášť | |
|---|---|---|---|---|
| Teplosměnná plocha | | 18,4 | | m² |
| Faktor znečištění | | 0,0002 | | m²K/kW |
| k čistý | | 1213,1 | | W/m²K |
| k znečištěný | | 1212,7 | | W/m²K |
| Rezerva | | 0 | | % |
| Vypočt. tlak. ztráta | 8,8 | | 1,2 | kPa |
| Tlaková ztráta na hrdle | 0,0 | | 0,0 | kPa |
| Rychlost na hrdle | 0,17 | | 0,19 | m/s |
| Vnitřní rychlost | 0,57 | | 0,22 | m/s |
| Reynoldsovo číslo | 7576 | | 849 | - |
| Koefic. přest. tep. | 3054,0 | | 2176,8 | W/m²K |

## FYZIKÁLNÍ VLASTNOSTI:

| | Strana 1 - Trubky | Strana 2 - Plášť | |
|---|---|---|---|
| Médium | Water | Water | |
| Ref. teplota | 55,0 | 32,5 | °C |
| Hustota | 988,14 | 996,66 | kg/m³ |
| Tepelný obsah | 4,18 | 4,19 | kJ/kgK |
| Tepelná vodivost | 0,638 | 0,610 | W/mK |
| Dyn. viskosita | 0,0005 | 0,0008 | Ns/m² |
| Prandtlovo číslo | 3,35 | 5,20 | - |

# SECESPOL - TECHNIKÝ LIST VÝMĚNÍKU TEPLA

| | |
|---|---|
| **Typ výměníku tepla** | **JAD X 12.114 MF.STA.CS** |
| **Katalogové číslo** | **0130-0001** |

## PRACOVNÍ PARAMETRY:

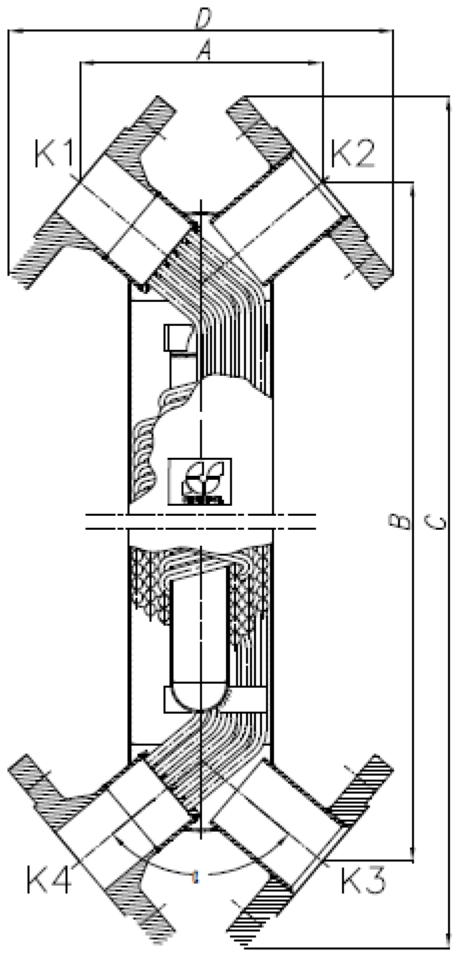
| | Strana trubek | Strana pláště | |
|---|---|---|---|
| Maximální tlak | 25 | 16 | bar |
| Maximální teplota | 250 | 203 | °C |
| Minimální teplota | 0 | 0 | °C |
| Skupina média | 2 | 2 | |

## KONSTRUKČNÍ PARAMETRY:

| | | |
|---|---|---|
| Typ teplosměnné plochy | Hladká trubka 8,0 mm | |
| Teplosměnná plocha | 18,4 | $m^2$ |
| Objem trubkovnice | 20,1 | l |
| Objem pláště | 54,2 | l |
| Hmotnost | 156,0 | kg |
| SKUPINA MATERIÁLŮ: | SS 18-10 | |

## STANDARDNÍ ZAPOJENÍ:
## (protiproud)

K1 - vstup topného média
K2 - výstup ohřívaného média
K3 - vstup ohřívaného média
K4 - výstup topného média




## ROZMĚRY:

| | | |
|---|---|---|
| A | 344,0 | mm |
| B | 1681,0 | mm |
| C | 1883,0 | mm |
| D | 484,0 | mm |
| Dz | 273,0 | mm |
| alfa | 110,0 | mm |

## TYPY PŘIPOJENÍ:

K1 - Krková příruba CS DN125 PN40 TYP 11B
K2 - Plochá příruba CS DN125 PN16 TYP 01B
K3 - Plochá příruba CS DN125 PN16 TYP 01B
K4 - Krková příruba CS DN125 PN40 TYP 11B

**Source – Secespol – CZ, s.r.o.**

**Attachment No. 11**

**Source – Michal Janča**