Master Brewers Association of the Americas

Dedicated to the technology of brewing.

2014 MBAA Annual Conference

Thermal Process Engineering for Brewers

Basics in Theory and Practice

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Why is a Basic Knowledge important for Brewers?

- Heat exchange can be found everywhere in the brewery!

Heating up the mash and hold the temperature break

Wort boiling

Why is a Basic Knowledge important for Brewers?

- Heat exchange can be found everywhere in the brewery!

Wort cooling

Heat transfer between a tank and its environment (for instance brewing liquor)

Why is a Basic Knowledge important for Brewers?

- Heat exchange can be found everywhere in the brewery!

Fermentation and beer storage

Flash pasteurization

Why is a Basic Knowledge important for Brewers?

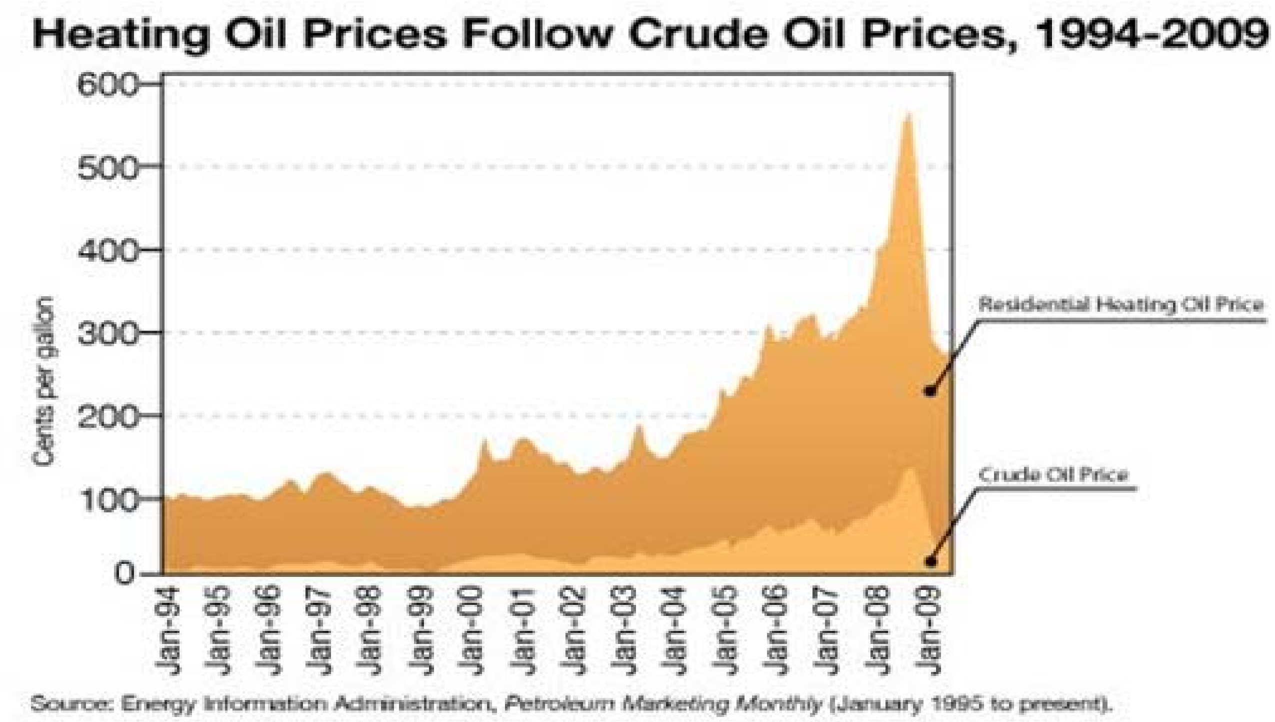
- Average heat/cooling consumption of a 83,000 bbl brewery (100,000 hl)

Heat consumption of the brewhouse:	22.5 kWh/bbl sales beer
Of that mashing (infusion):	3 kWh/bbl sales beer
Of that boiling (10% total evaporation):	13.5 kWh/bbl sales beer
Heat consumption of the whole brewery:	44.1 kWh/bbl sales beer
Cooling consumption of the whole brewery:	7.7 kWh/bbl sales beer

>50% of the total heat is consumed in the brewhouse!

Why is a Basic Knowledge important for Brewers?

- Heating oil price development in the past



➢ The price for heating oil rose in the past and will be unstable in the future!

Why is a Basic Knowledge important for Brewers?

- Heat transfer is part of many processes during beer production.
  - The knowledge about the physics behind processes is important to ensure high product quality.
  - It also offers the opportunity to improve your wort-/beer taste.
  - Understanding heat transfer means recognizing potential to save money in the future.
  - Saving primary energy means to be more independent of the uncertain development of heating oil prices.
  - Additionally, CO_2-Emission may be decreased.

USA TODAY 6/2/14

EPA wants carbon cut 30%

Plan would reduce emissions as part of climate-change fight

Wendy Koch
USA TODAY

The Environmental Protection Agency will unveil a sweeping proposal today that will require deep cuts in carbon emissions from existing power plants, including a 30% national target by 2030, according to two people briefed on the plan.

The EPA draft rule, a major plank of President Obama's initiative to fight climate change, will require states to develop and implement plans to cut power plant emissions of heat-trapping carbon dioxide. It will give states different reduction targets but will seek a national average — from 2005 levels — of 25% by 2020 and 30% by 2030, say those familiar with the plan.

Last June, Obama asked the EPA to use its authority under the Clean Air Act to limit power plants emissions, which account for the largest share — nearly

If the plan succeeds, "we'll all be paying a lot more money for electricity — if we can get it."

Sen. Mike Enzi, R-Wyo.

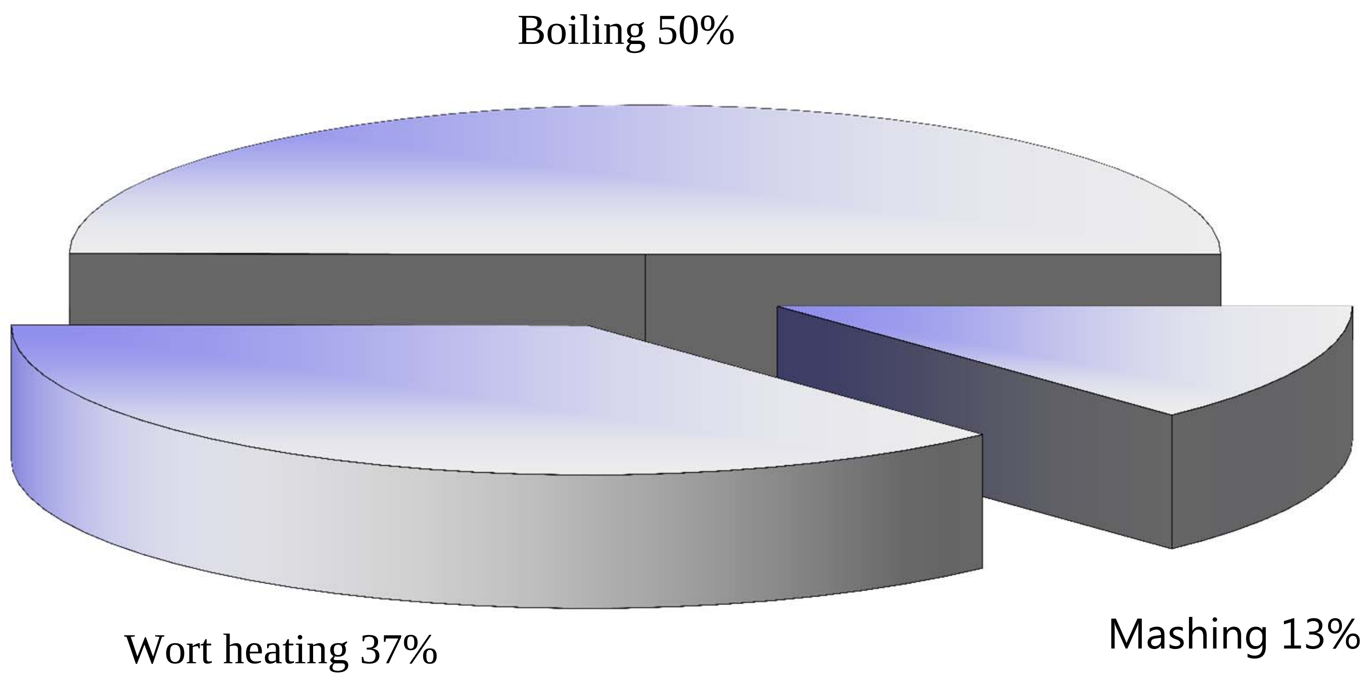
40% — of total U.S. emissions. Coal-fired facilities will be hardest hit.

The rule, expected to trigger legal challenges, will not take effect for at least two more years. Obama has asked the EPA to finalize it in June 2015, after which the states will have at least a year to craft their plans.

In his Saturday radio address, Obama said cutting carbon emissions will reduce air pollution, improve health and spur a clean energy economy that can be "an engine of growth."

In the GOP

CO2 EMMISION DURING WORT PRODUCTION



Summery energy demand wort production
(10 HL k.o.; 7 brews/week; 336 brews/a)

	Energy demand	Energy cost	CO_2 emission
Mashing	3,385 kWh/a	$790/a	2,022 lb/a
Wort heating	9,649 kWh/a	$2,250/a	5,766 lb/a
Boiling	13,002 kWh/a	$3,033/a	7,070 lb/a
Total	26,036 kWh/a	$6,073/a	15,558 lb/a

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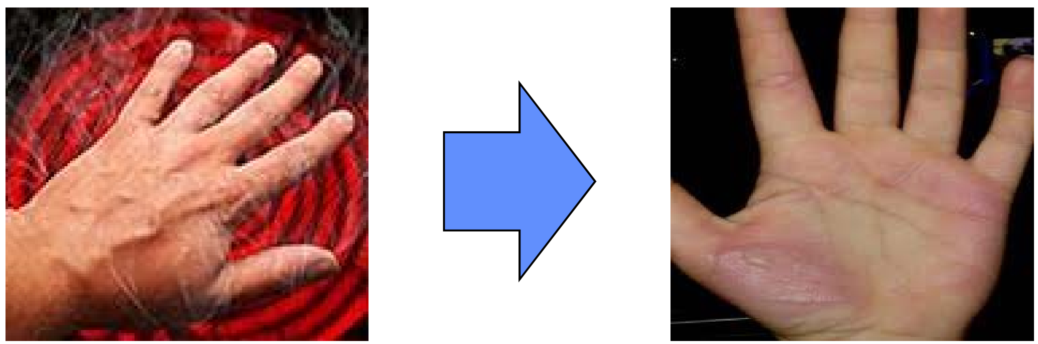
Heat and Energy

- What is heat?

Heat (abbreviation Q) is energy that is being transferred based on a temperature difference of a system and its environment (or between two systems) across the common system boarder.



Heat comes from the higher temperature level to the lower temperature level. The results are often serious.

- Therefore, heat always flows from the system with a higher temperature level to the system with lower temperature level (according to the second law of thermodynamics).

- Heat flow ($\dot{Q}$)is determined as the transferred heat in a certain time interval. It can be considered the same as the thermal power.

Heat and Energy

- Heat is transferred energy. But how is energy defined?
- Example: What contains more energy: a cup of hot soup or a glass of beer?

- Obviously, the soup has got more energy because of its higher temperature.

> Energy is the ability of a system to work or to release heat.

Definition of Thermodynamic Parameters

- Specific heat capacity c_p (also called specific heat):
  - The specific capacity describes which quantity of heat is required to rise the temperature of 1 kg of a certain substance by 1 Kelvin. The physical unit is $\frac{kJ}{kg \cdot K}$.
  - The c_p value only applies for a certain pressure.

Fluid	c_p $[\frac{kJ}{kg \cdot K}]$ for atmospheric pressure
Water	4.18
Mash (15 °P)	3.73
Mash (20 °P)	3.60
Mash (25 °P)	3.46
Wort	4.0 – 4.1
Air	1.005

- **With increasing density of the mashes, the specific heat decreases.**

Definition of Thermodynamic Parameters

- Specific Enthalpy h:
  - Enthalpy means the content of heat in a body. The specific enthalpy is the heat in relation to mass $[\frac{kJ}{kg}]$. For fluids applies:

$$h = c_p \cdot \Delta T$$

T: Temperature

  - Enthalpy of vaporization/-condensation r $[\frac{kJ}{kg}]$ is the content of heat that is required/released for changing the state of aggregation from liquid to vapor state and vice versa. The amount of enthalpy depends on the pressure level of the system (vapor pressure!). For condensing saturated steam applies:

$$h = r$$

Pressure of the system (abs.)	r $[\frac{kJ}{kg}]$ for water/vapor transformation
1.0	2,257.9
1.5	2,226.2
2.0	2,201.6
5.0	2,107.4

Thermal Energy and Power

- How can you calculate the energy of a fluid?

Generally:	$Q = m \cdot h$
For fluids:	$Q = m \cdot c_p \cdot \Delta T$
Saturated steam:	$Q = m \cdot r$

m: Mass of the material

- The required thermal power can be found by considering the time to heat up a body/fluid:

$$\dot{Q} = \frac{Q}{t}$$

t: Time

Heat Transfer

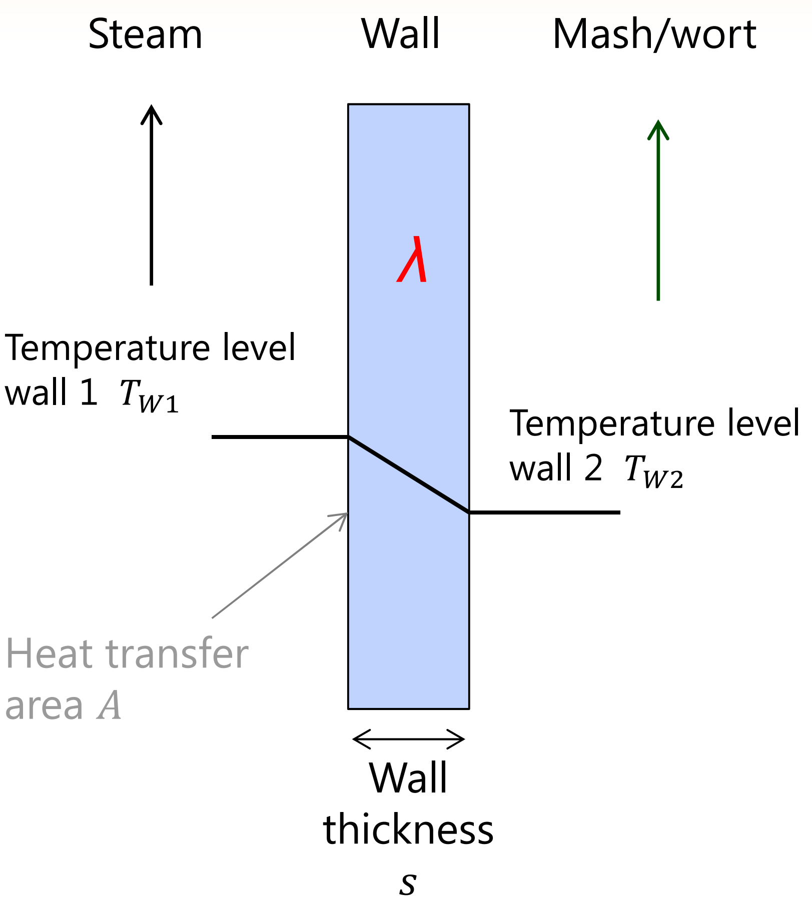
- 3 possibilities of transferring heat through a vessel wall:
  - Heat conduction
  - Convection
  - Heat radiation (not considered in this presentation, but in fact has influence on wort boiling and cooling outdoor fermentation tanks)

> In reality, there is always a combination of the three types.

Heat Transfer

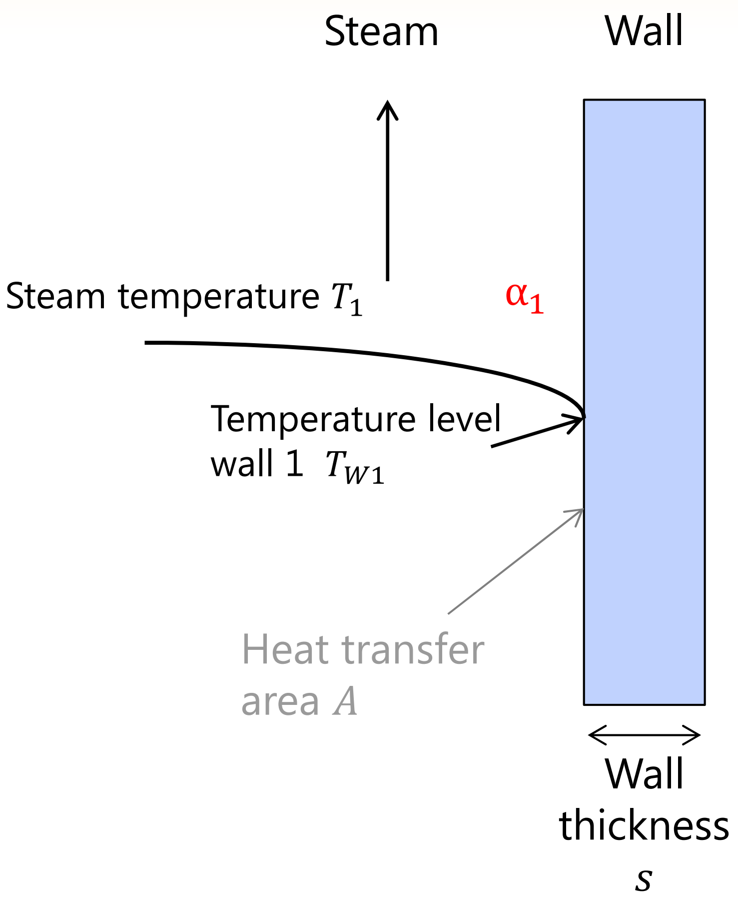
- Heat conduction and thermal conductivity λ
  - Material property that describes how big the temperature difference between the in- and outside of a wall is.
  - $\dot{Q} = \lambda \cdot \frac{A}{s} \cdot (T_{W1} - T_{W2})$

Material	$\lambda[\frac{W}{m \cdot K}]$ for 68 °F
Stainless Steel	15
Copper	380
Aluminum	229
Silver	410



Heat Transfer

- Convection
  - The convection coefficient (α) describes the ability of a fluid (gas) to gather / release energy from / to the surface of a wall.
  - $\dot{Q} = \alpha_1 \cdot A \cdot (T_1 - T_{W1})$
  - α (physical unit $\frac{W}{m^2 \cdot K}$) can be specified by experiments using dimensionless numbers (e.g. Reynold's number).
  - α-value depends on:
    - Material properties (of the wall and of the fluid)
    - Fluid flow near the wall (higher turbulents result in better α)

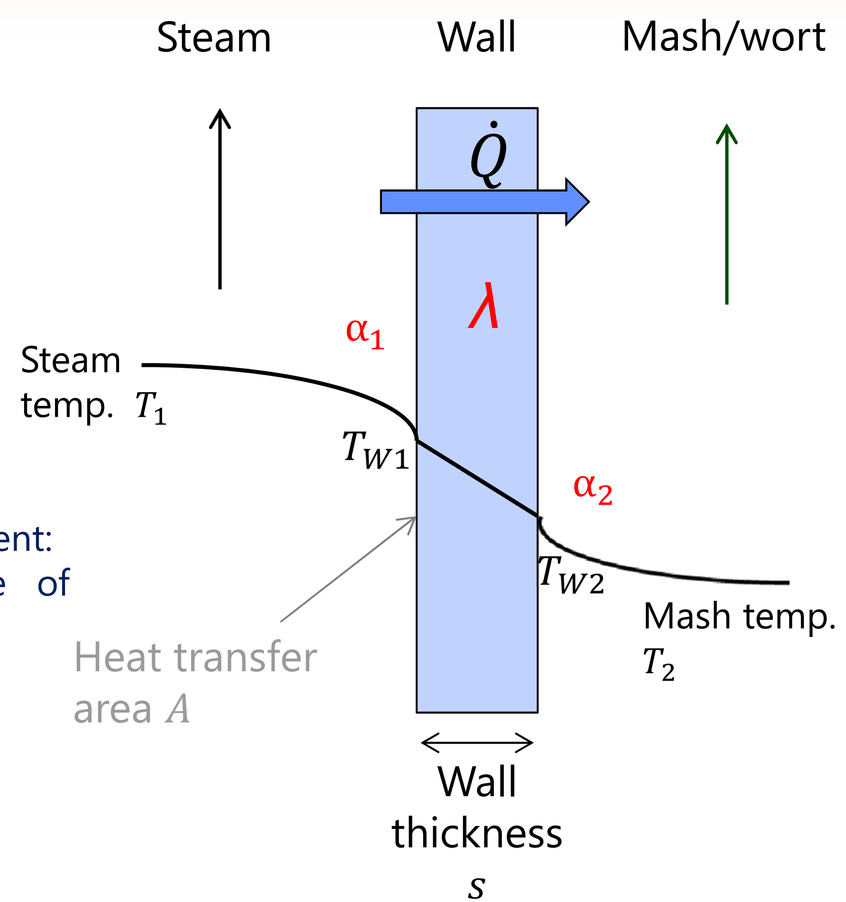


Heat Transfer

- The real heat transfer:
  - In real heating (and chilling!) processes, a combination of conductivity and convection takes place.
  - The whole heat transfer is characterized by the k-value.
  - $k = \frac{1}{\frac{1}{\alpha_1} + \frac{s}{\lambda} + \frac{1}{\alpha_2}}$
  - $\dot{Q} = k \cdot A \cdot (T_1 - T_2)$

Temperature gradient: The driving force of heat transfer

  - Conventional mash tuns obtain a k-value of 1,000 – 1,500 $\frac{W}{m^2 \cdot K}$

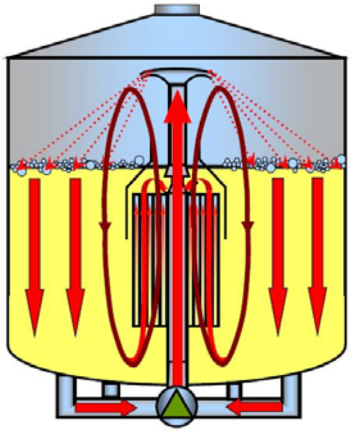


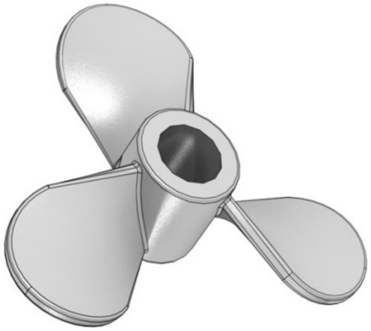
> The k-value is a dimension that estimates whether much or less heat is transferred

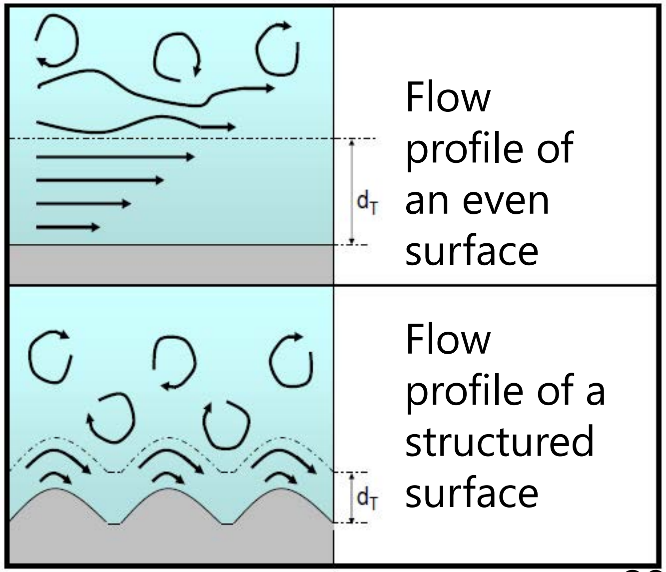
How can Brewers improve the k-value and the Heat Transfer?

- Basically, the higher the turbulences in the product and the heating medium, the better the k-value.

- Possibilities for higher turbulences:
  - Proper agitation during mashing, including a fitting agitator shape (propeller mixer)
  - Special surface of the mash tun/kettle
    - Pillow Plates; increasing of the heat exchange area (k-value: $2{,}000\,\frac{W}{m^2 \cdot K}$)
  - Using a circulation pump during boiling.
  - Avoid fouling and calcification! Correct and proper cleaning of the tanks is important!
  - Shape of the heating/cooling pipes.
  - Improved shape of the heat exchanger plates of the wort cooler or flash pasteurizer.







Pillow Plates

The thickness of the dimple surface is 1.5 mm and the thickness of the shell (outer) is 5 mm

KRONES has the system since 2003 on the market and has since build an average of 30 units per year in sizes between 2.0 and up to 7.5 mm.

The first one went in at Leipziger Brauhaus in Leipzig and is under constant review. KRONES specialist check the thickness of the surface every year, and to date is no reduction due to abrasive actions or anything else. The Brewery is brewing 12 brews/day since it was installed.

Thanks for your attention!