Theory of Heat Exchange

How and Why Driving Energy is Important in the Brewhouse

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Welcome to the Opening Act!

Why Boil?

Sterilize Wort

Denature enzymes

Stabilize

Isomerize α-acids

Flavor development

Color development

Volatilize aromatics

Concentrate

What are the Objectives?

Heat Wort

$$Q_1 = MC_p\Delta t$$

What are the Objectives?

Heat Wort

M = Mass of wort

C_p = Specific heat

Δt = Temperature differential

What are the Objectives?

Evaporate Water Vapor

$$Q_2 = Mh_f$$

What are the Objectives?

Evaporate Water Vapor

M = Mass of wort

h_f = heat of vaporization

What Does “Q” Represent?

Total energy required to heat wort before boiling and evaporate water during boiling.

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Total energy required to heat wort before boiling and to evaporate water during boiling.

“Q” does not tell us anything about heating rate, efficiency, etc.

Heat Sources

- Hot Oil
  - *Remote heating source*
  - *High Δt without pressure*
  - *Not common today*

Heat Exchange Type

- Hot Oil
    - *Heating jacket or coil*

Heat Sources

- Hot Water
  - *Remote heating source*
  - *High Δt requires pressure*
  - *Not common today*

Heat Exchange Type

- Hot Water
  - *Heating jacket or coil*

Heat Sources

- Direct Fire
  - *No remote piping required*
  - *Very high Δt*
  - *Works better with copper*
  - *Inefficient use of fuel*
  - *Lower initial investment*
  - *Not uncommon today*

Heat Exchange Type – Direct Fire

- *Firebox*
- *Internal coil*

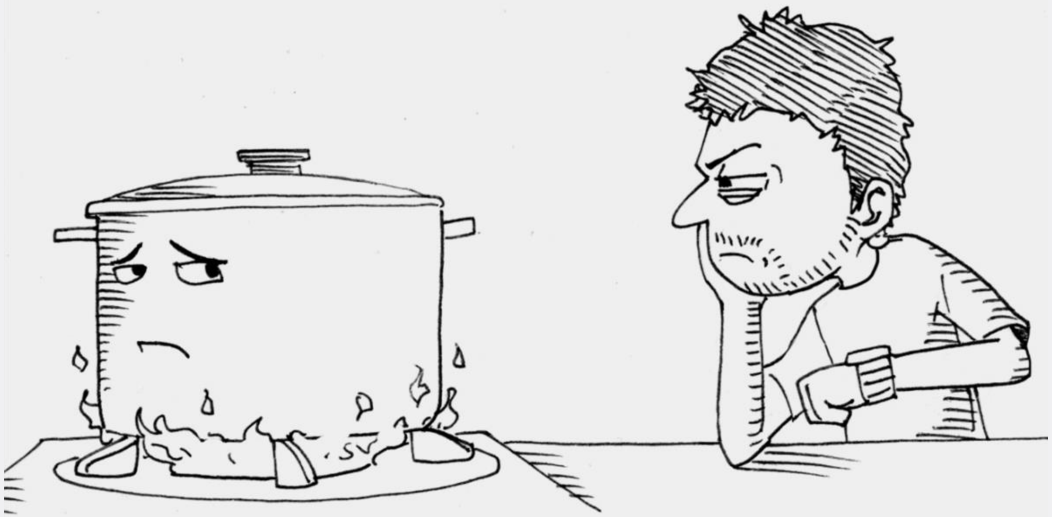
Heat Sources

- Steam
  - *Remote heating source*
  - *Has latent heat*
  - *Q not solely dependent on ΔT*

Heat Exchange Type - Steam

- *Heating jacket or coil*
- *Heat exchangers*
    * *Internal calandria*
    * *External calandria*
    * *Hybrid types*

Let's Do it Quickly!



Heat Transfer Rate

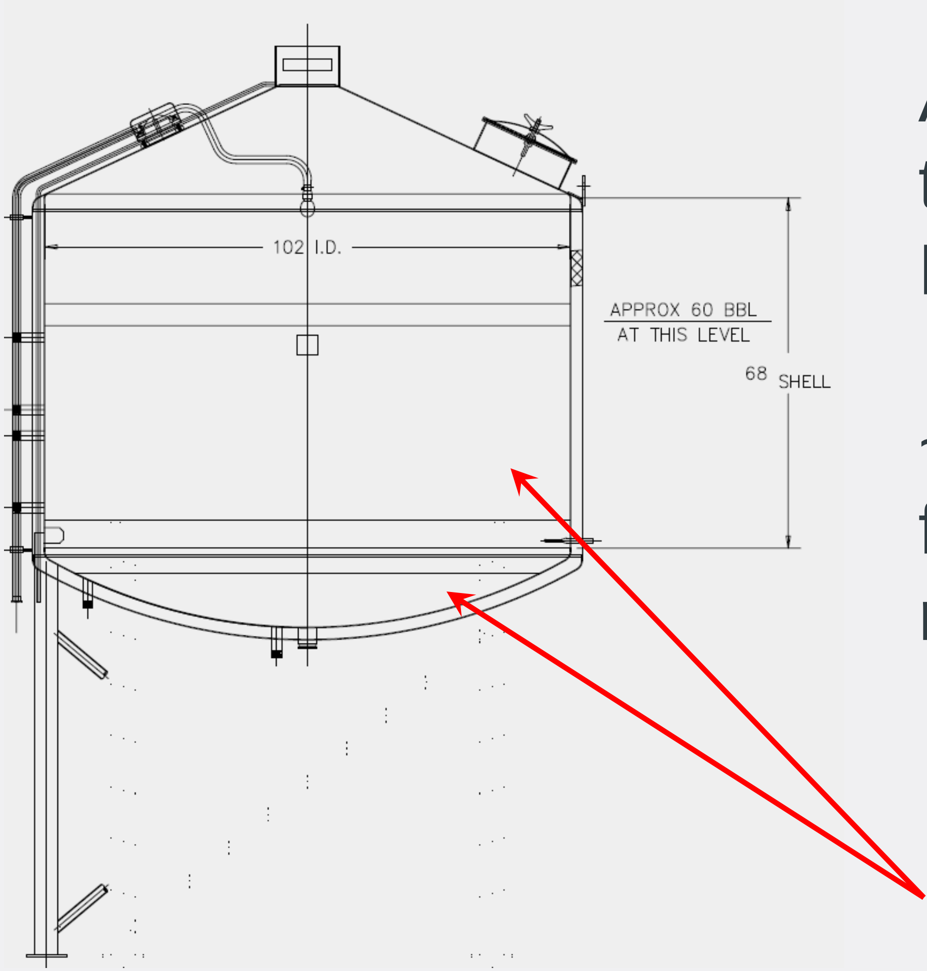
$$\frac{\Delta Q}{\Delta t} = q = \frac{UA\Delta T}{d}$$

Q = heat flow
t = time
q = heat transfer rate
U = overall heat transfer coefficient
A = area
T = temperature
d = material thickness

Design Strategy #1

Add Area

Area Limitations & Jacketed Kettles …



Available area limits this type of design to about 60 BBLs

~2.3 ft^2 / BBL is needed for hourly evaporative rates >6%

2.3 ft2 / BBL total area


I NEED
MORE
AREA!!!

More Area!

Percolators

External Calandrias

Internal Calandrias

Hybrid Designs

Design Strategy #2

Design Strategy #2

U-Value

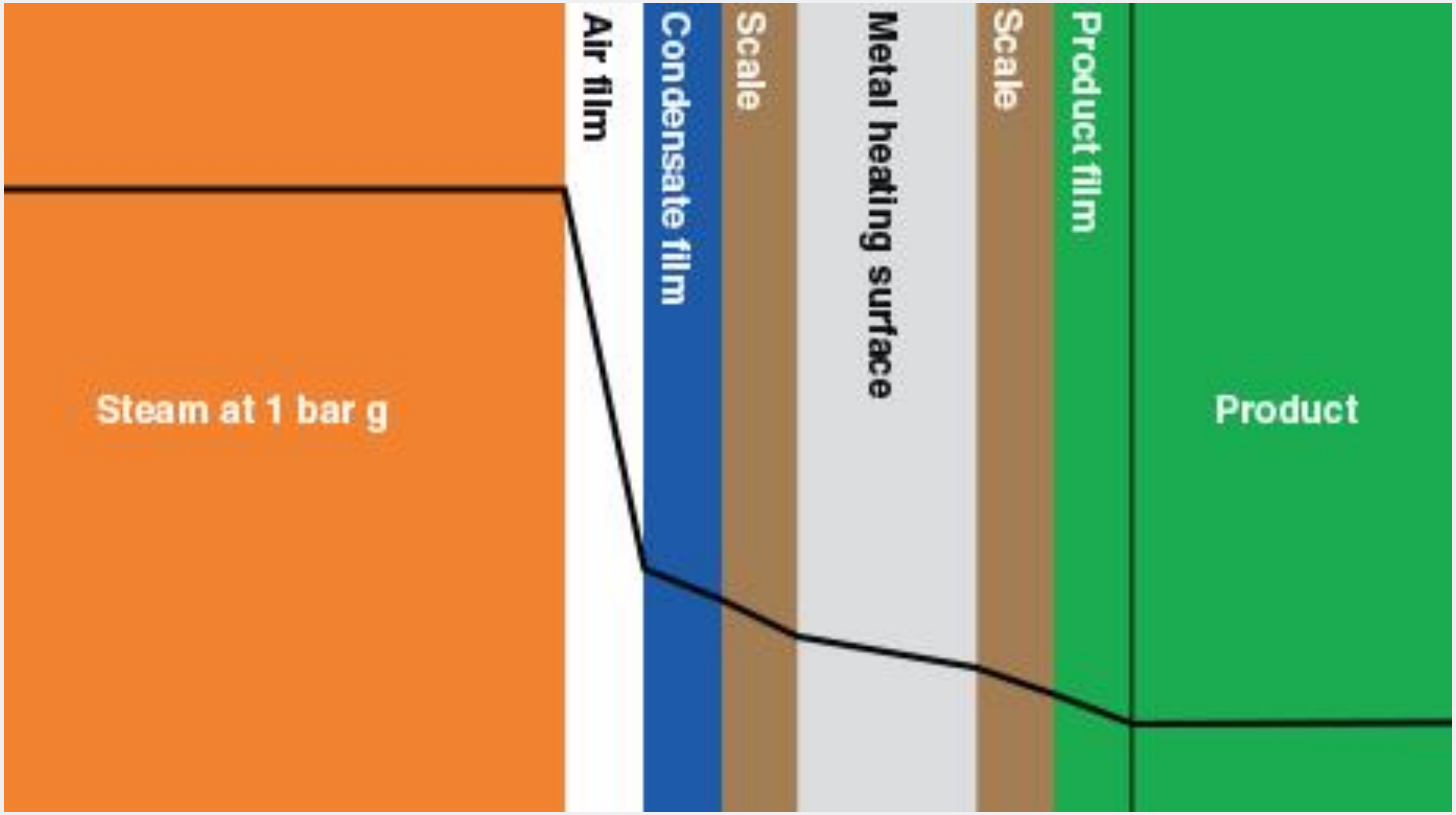
$$\frac{1}{\mathrm{U}} = \frac{1}{h_o} + \frac{1}{k_w} + \frac{1}{h_i}$$

$h_o =$ convective heat transfer coefficient product side

$k_w =$ thermal conductivity of heat transfer surface

$h_i =$ convective heat transfer coefficient utility side

Steam Heat Flow Profile



http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/steam-engineering-principles-and-heat-transfer/heat-transfer.aspx

Increasing U-Value

1. Change heat transfer surface

k_{copper} ~ 400 W/mK

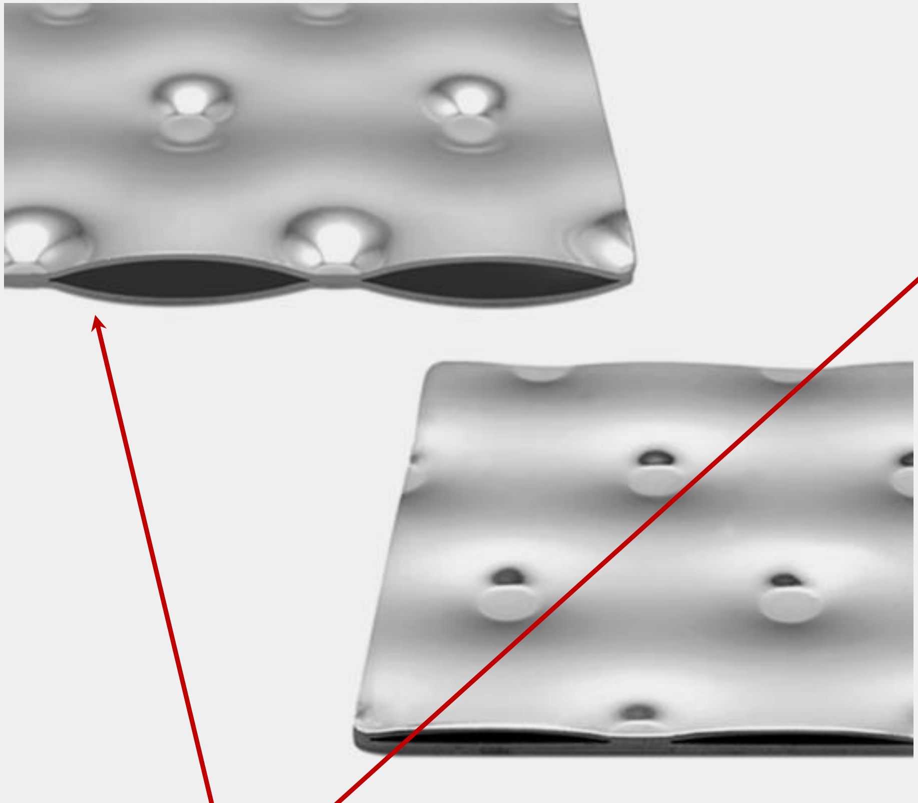
$k_{stainless}$ ~ 17 W/mK

Increasing U-Value

1. Change heat transfer surface

2. Increase turbulence at heat transfer surface

Turbulence



Turbulence on both sides of heat transfer surface

Surface shape
Pumps
Mixers
Baffles

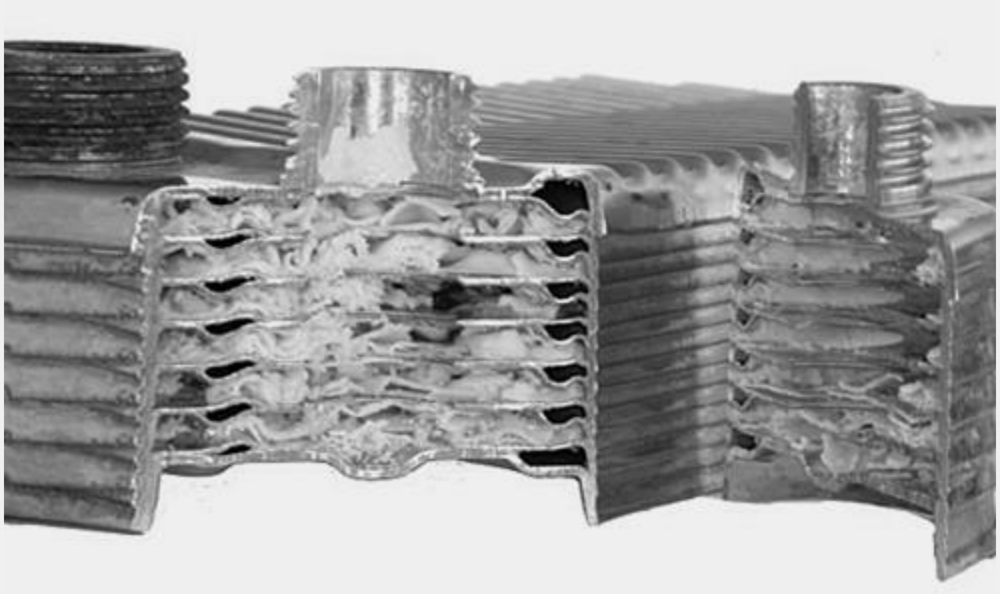
Increasing U-Value

1. Change heat transfer surface

2. Increase turbulence at heat transfer surface

3. Keep it clean (scales, soils & air)

Examples of Fouling



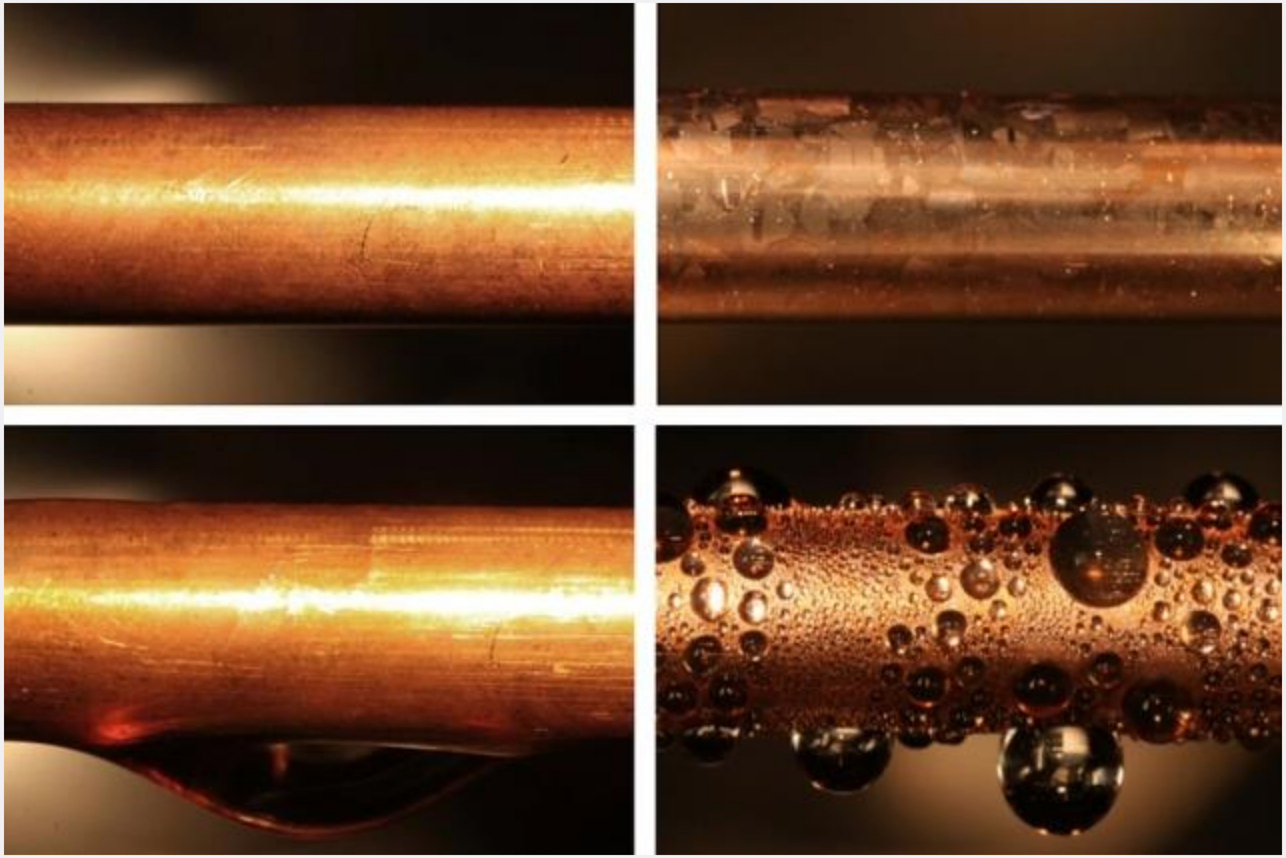
Reduces U
Can also reduce A

Increasing U-Value

1. Change heat transfer surface
2. Increase turbulence at heat transfer surface
3. Keep it clean
4. Change the surface properties

Surface Properties

Film Condensation Dropwise Condensation



Graphene film on copper tube increases U 4X

http://news.mit.edu/2015/graphene-coating-more-efficient-power-plants-0529

Surface Properties

Very clean stainless steel heat transfer surfaces, especially those that are very smooth, can reduce overall heat transfer.

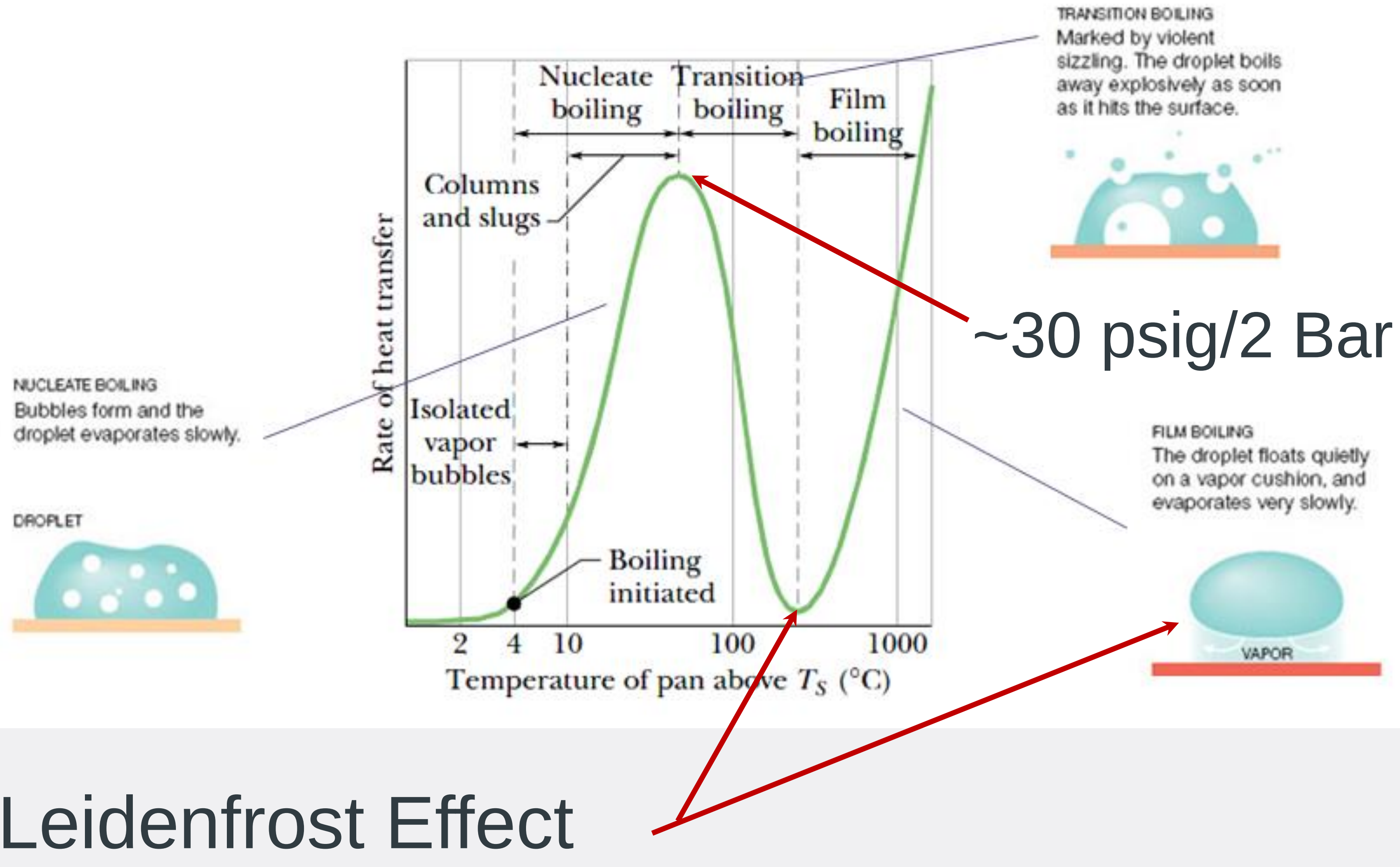
This may seem counterintuitive.

Considerations When Using Steam

Excessive surface temperature increases fouling & thermal stress, especially during pre-boil heating phase, and reduces heat flux above the critical point.

Heat transfer for water (@ 1 atm)

S-shaped graph when heat flux (q”) is compared to temperature.



Thiobarbituric Acid Index

Thiobarbituric Acid Index is a summary index that measures Maillard reaction products with a colorimetric metric.

Sample + acetic acid + TBA held 70°C for 70 minutes. Measure absorbance at 448 nm and compare to control prepared without TBA.

TBI = ΔAbsorbance x 10 x dilution factor

Considerations When Using Steam

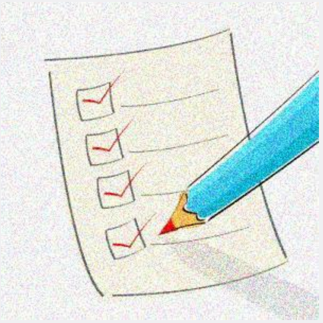
Excessive pressure increases fouling & thermal stress (TBA / TBZ value), especially during pre-boil heating phase

Condensate reduces area when not removed properly

Stalled traps

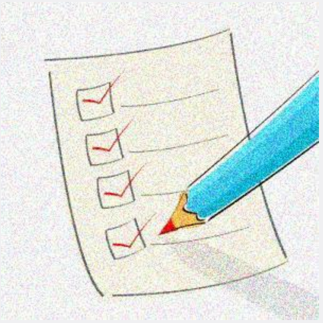
Flow/mass control and measurement

Summary Points



- Modern kettles are steam heated

Summary Points



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- The trend is towards using lower steam pressure with lower total evaporative rates

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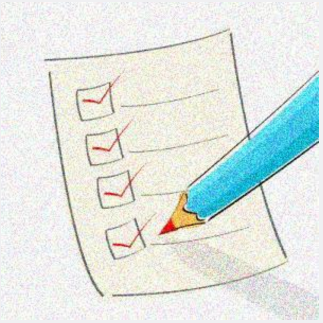

- Modern kettles are steam heated
- The trend is towards using lower steam pressure with lower total evaporative rates
- Technological advances are generally focused on ways to increase U-Value and further the goals of boiling while reducing overall energy consumption

Thank You for the Opportunity!

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