Brewhouse & Heat Energy Integration

IBD Midlands Section Engineering Symposium on Engineering Design & Sustainability

DCCC Derby – Jan 2017

John Hancock – Briggs of Burton

Brewhouse & Heat Energy Integration

- Brewhouse Process
- Mash Conversion & Heating
- Mash Separation
- Wort Pre-heating, Boiling and Energy Recovery
- Wort Cooling optimisation
- Heat Energy provision and balancing
- Pumps –
  - Selection & Efficiency
  - VSD operation

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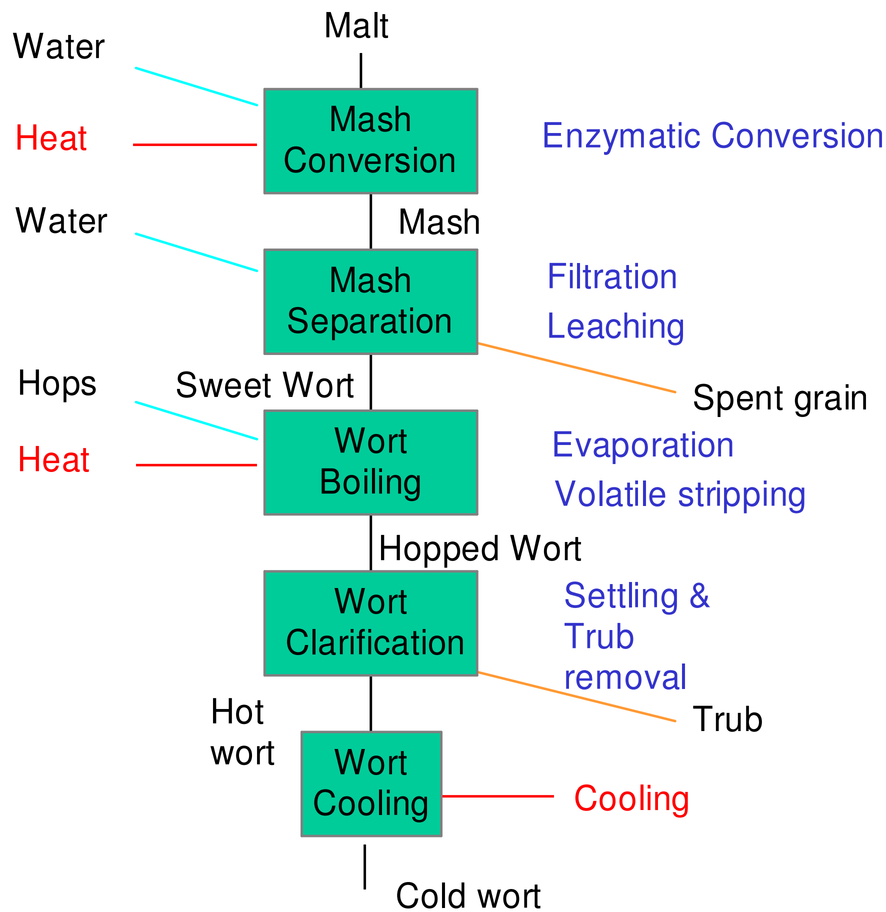
Brewhouse Process

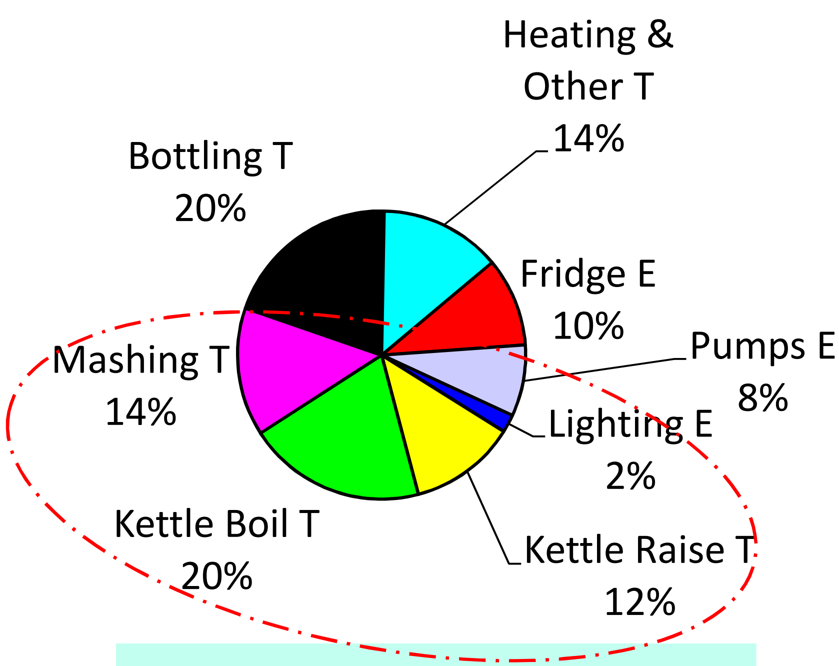
- Two major thermal energy input points
  - Mashing
  - Wort Heating & Boiling
- Mash separation
  - Extract efficiency
  - Pinch point
- Two major thermal energy recovery opportunities
  - Wort Boiling
  - Wort Cooling



Brewery Energy Usage

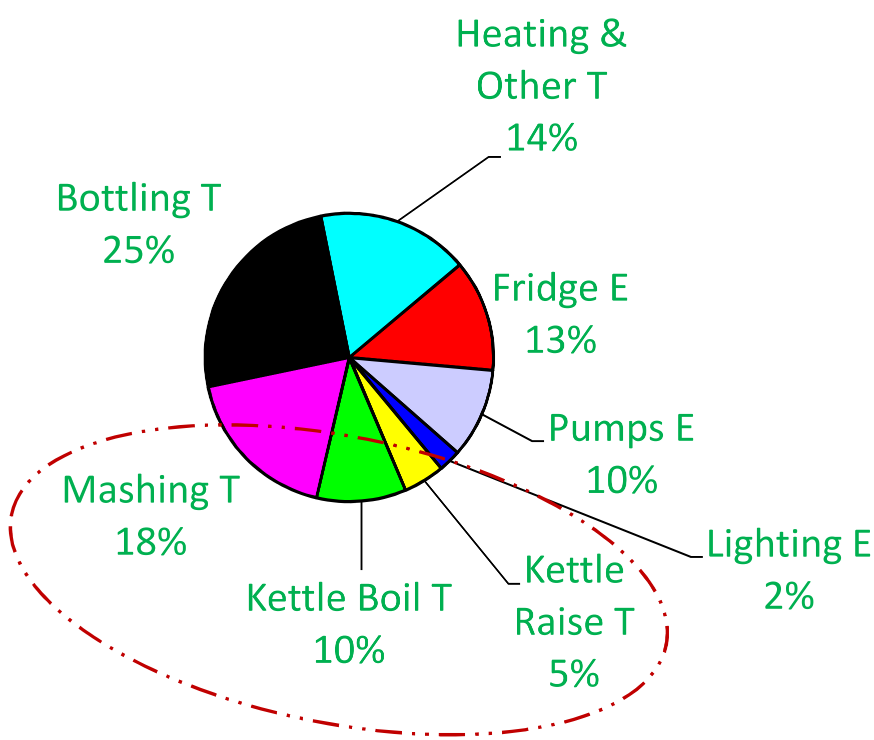
Brewhouse - Major Energy Users Mashing & Wort Boiling

Historical data for a 10% Boil without Energy Recovery



Beer Production - 125 MJ/hl

Same Data with 4% Boil with Wort Preheating using Energy Recovery



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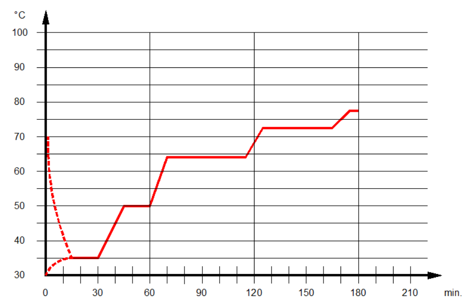
Mash Conversion & Heating - Objectives

- Mixing & wetting of grist with water
- Breakdown of proteins
- Starch Gelatinisation & Liquefaction
- Conversion of Starch to Sugars
- Optimise enzyme activity
- Retain malt husk
  - as a filter aid in Mash Separation

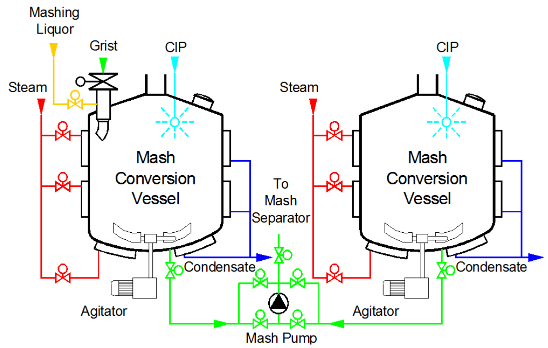
Heating and Temperature control essential

Mashing – Alternative Processes

- All Malt :
  - *Infusion Mash Tun*
    (minimal energy input)
    or

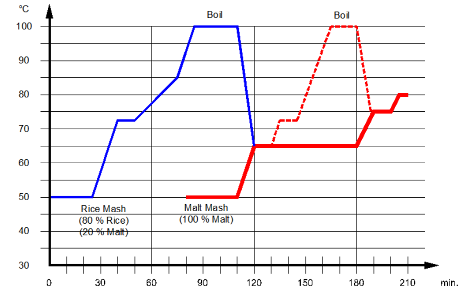


  - Programmed Infusion – Mash Vessel
    - To feed separate Lauter Tun or Mash Filter
    - Mash in at around 65°C, lower energy input



  - Decoction - Mash Kettle + Mash Vessel
    - To feed separate Lauter Tun or Mash Filter
    - More energy intensive

- Malt + Adjuncts :
  - Cereal cooker & Mash Vessel
    - Low shear mixing & transfer essential
    - Energy intensive



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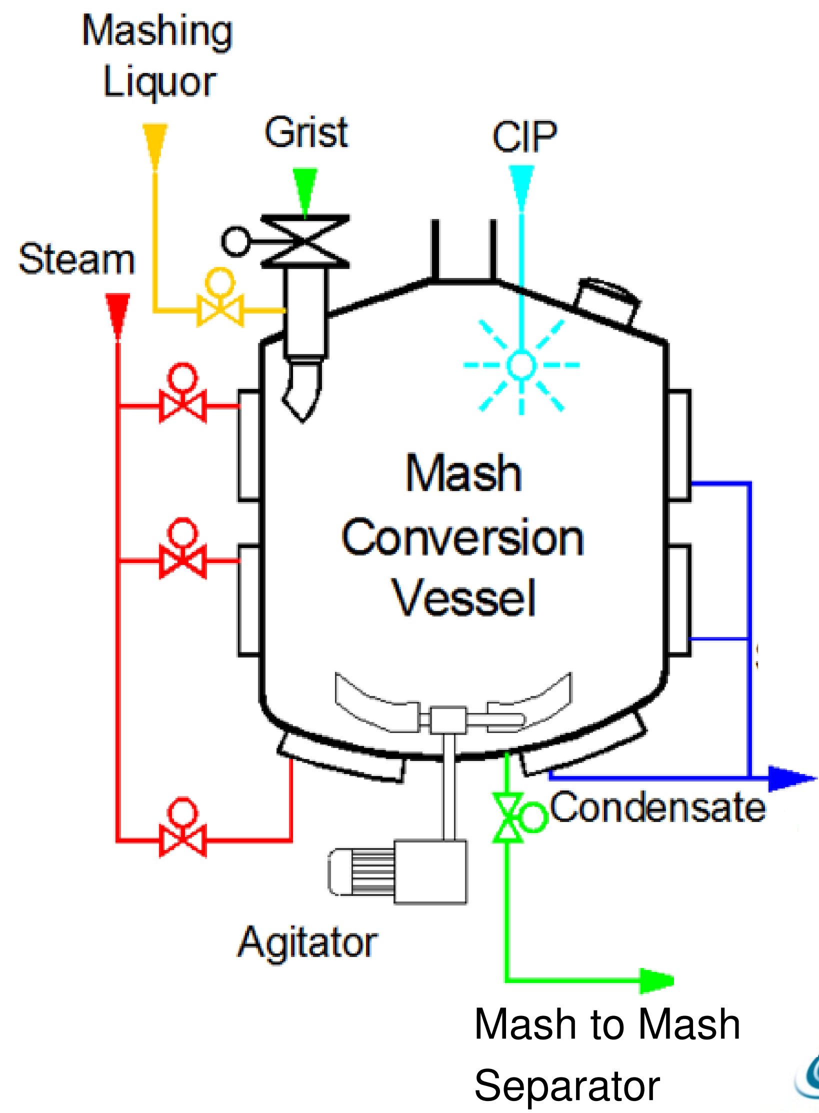
Mash Conversion & Heating - Features

- Pre-masher
  - Vortex type shown
  - Steeles Masher
- Gentle low shear mixing
- Controlled heating
- Zoned jackets
- Low shear transfer pump system
- Effective CIP



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Grist Hydration - Pre-masher

Vortex Masher

- Grist mixed into swirling, turbulent water flow
- Low shear
- Simple - No moving parts to maintain

Steeles Masher

- Positive flow path
- Gentle mechanical mixing
- VSD Controlled
- Effective with –
  - fine grist
  - Low (thicker) mash ratio

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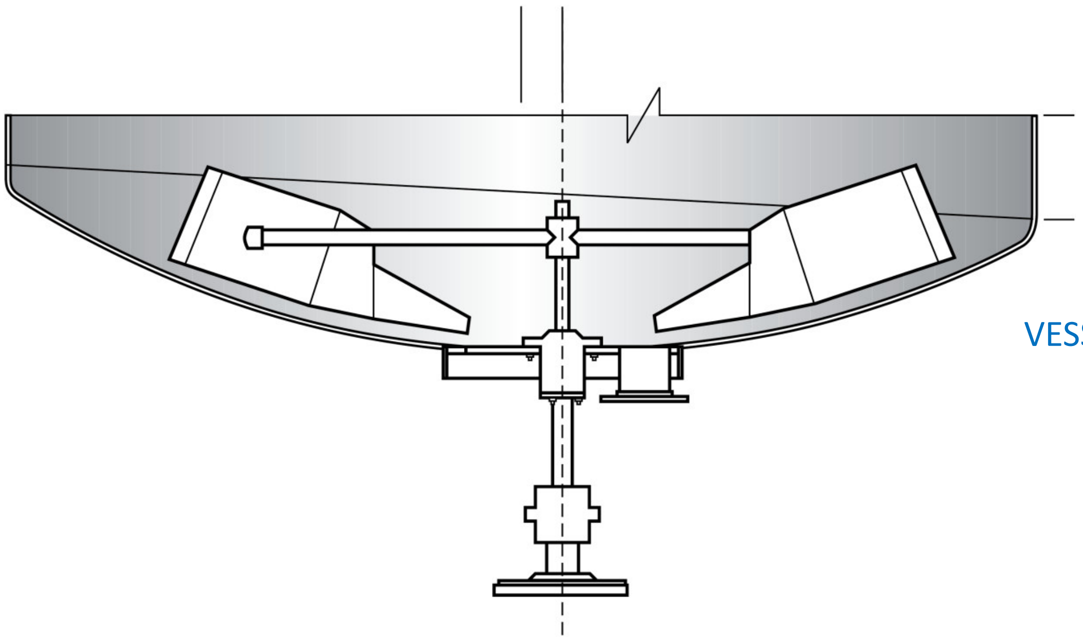
Mash Agitation - Minimising Mash Shear



Effective mixing needed to ensure homogenous mash with uniform temperature distribution.

Low Shear Mixing is a Combined Effect of Vessel Shape and Agitator

VESSEL SHAPE
- Low Aspect Ratio (Height : Diameter) 0.6 :1
- Tilted Dish
- No Internal Baffles

AGITATOR
- Large (85% of Vessel Diameter)
- Rotation - Slow - Max Tip Speed 3.5 m/s
- Mounted Off Centre (5 % Diameter)
- Variable Speed
  - Higher speed for Mashing & Heating
  - Slow Speed for Mash Stands > 55 °C
- Agitator close to base to ensure swept surfaces and avoid mash burn on

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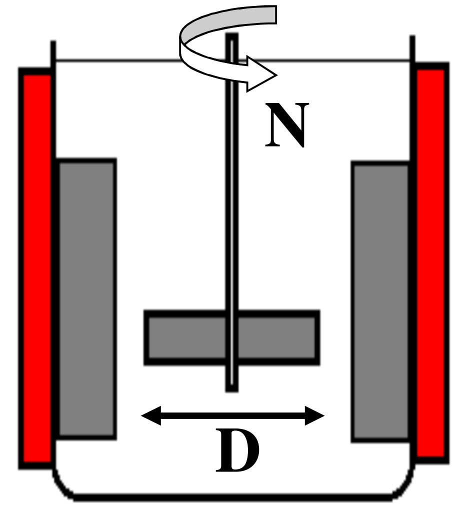
Mash Heating – Heat Transfer

- For Agitated Jacketed vessels, Forced Convection Heat Transfer is a function of *Reynolds* (Re) and *Prandtl* (Pr) Numbers (dimensionless) -



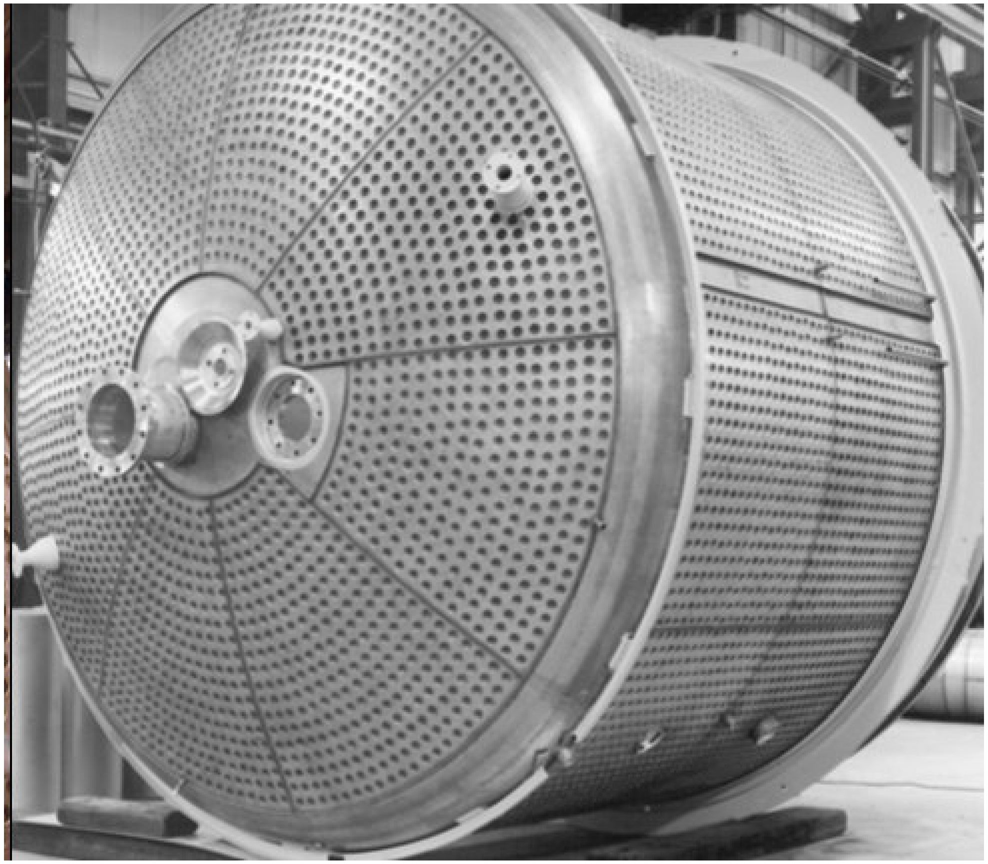
$$Re = \frac{\rho N D^2}{\mu}$$

$$Pr = \frac{c_p \mu}{k}$$

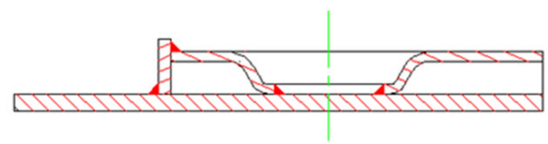
$$h = \left(\frac{k}{D}\right) 0.023 Re^{0.8} Pr^{0.4}$$

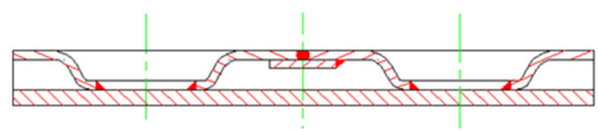
- Heat Transfer Coefficient (HTC) primarily dependent on turbulence / movement, in this case controlled by vessel / agitator system properties –
  - agitator diameter (D), agitator speed (N), and agitator type
- HTC also dependent on physical properties –
  - density (ρ), viscosity (μ), specific heat capacity (c_p) and conductivity (k)
  - For mash, viscosity is critical, especially for fine mash filter grist at low temperatures

Mash Heating - Dimple Jackets



- Welds located in a regular pattern
- Maintains strength using thin shell material
- Dimples impart turbulence
- Flow guiding system can be installed for liquid heating to increase contact time





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Mash Separation - Objectives

- Mash Filtration
  - Separation of Clear Wort from grain bed
  - Malt husks form a filter aid
    - More effective with coarse grist
- Sparging
  - Leaching of remaining extract from grain bed using hot Sparge water
    - More effective with fine grist
- Spent Grains Disposal - by-product
- Maximise Filtration & Sparging time
  - Minimise – Underlet, Mash-in, Grain out etc times

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Lauter - Design

- Lauter tun Size
- Mash Distribution
- Wort Collection
- Sparge Distribution
- Lautering
- Grains Discharge
- Underplate Flush

- Loading & Cycle time
- Low shear & Min O_2
- Even run-off
- Sparge Nozzles
- Knife design & speed
- Plough & Valves
- Jetting Nozzles

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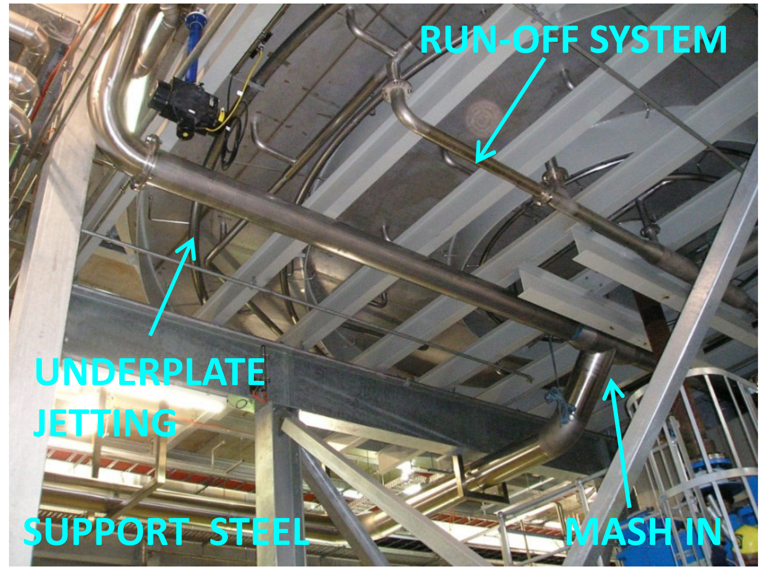
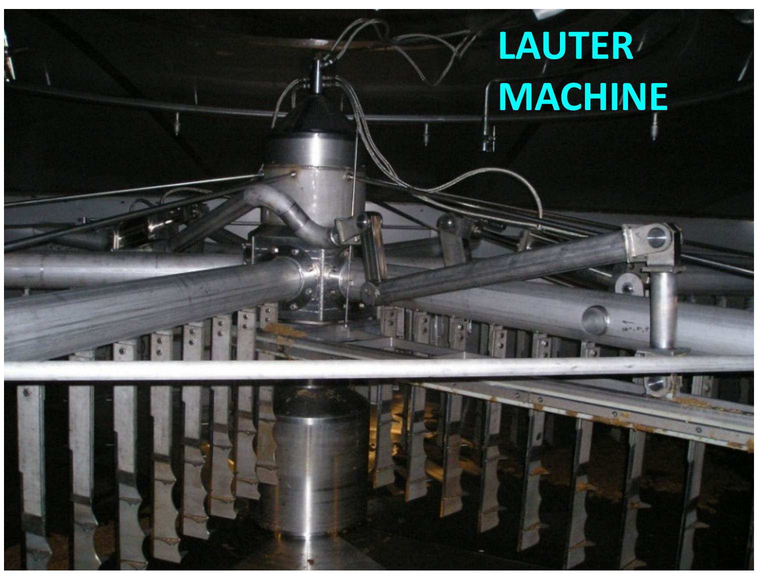
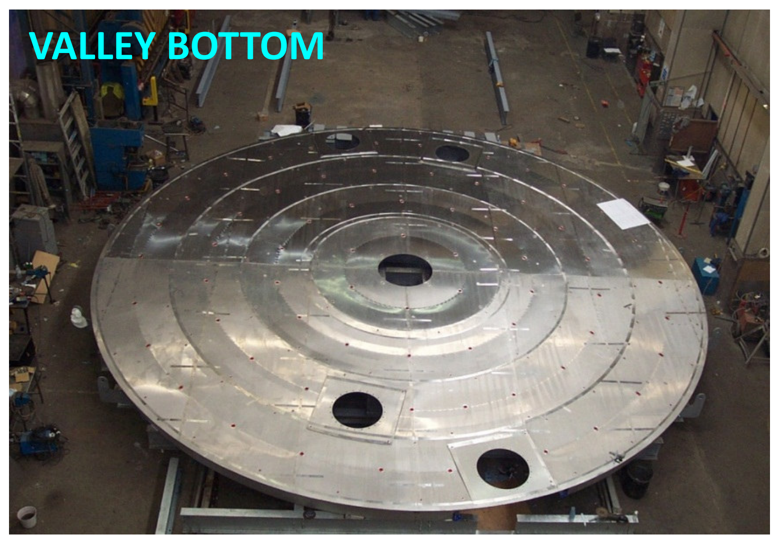
Lauter Tun







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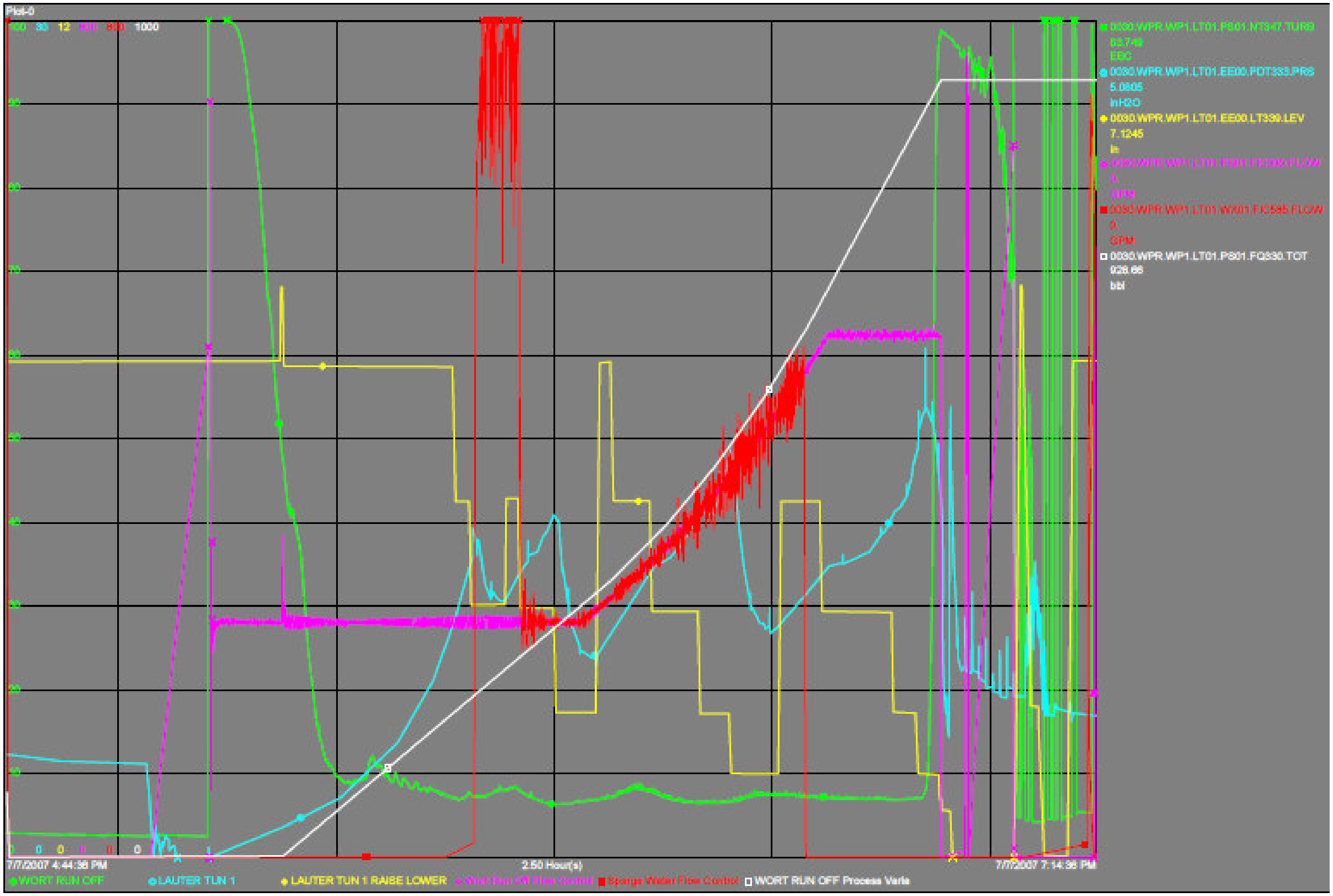
Brewery Lauter Tun Operation
12 Brews/Day at 160kg/m² - 12.8 m dia



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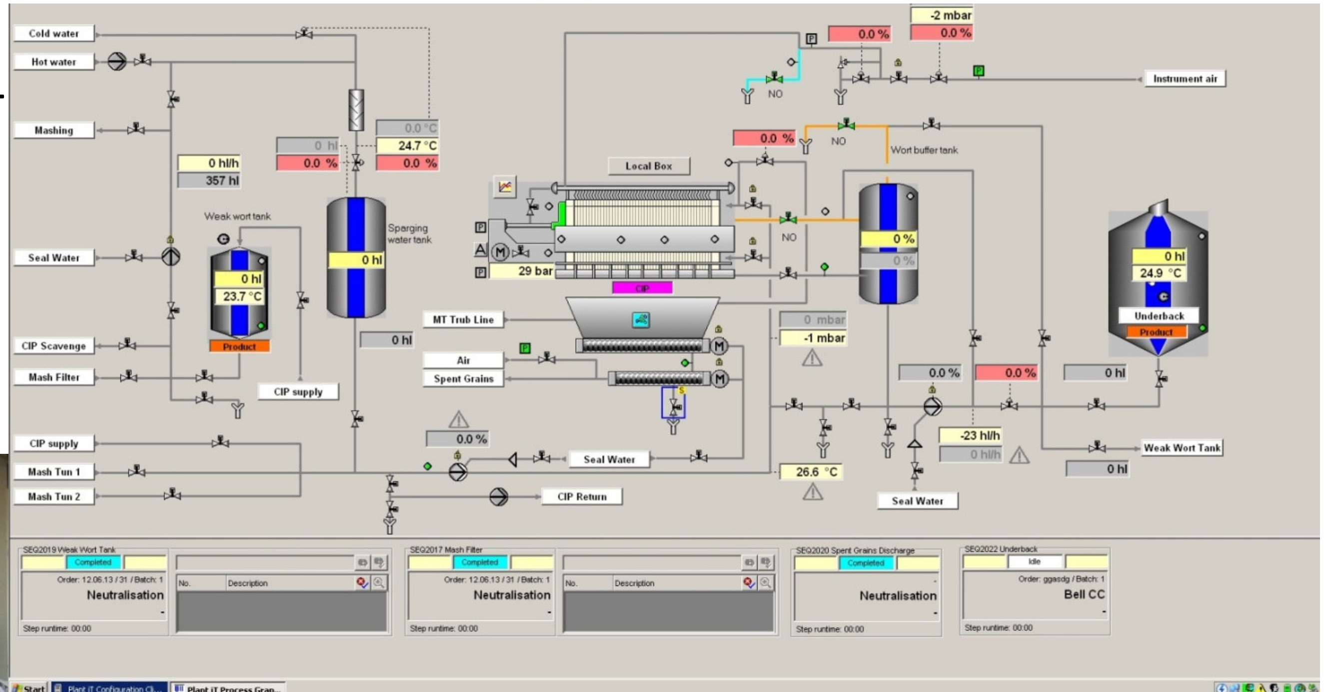
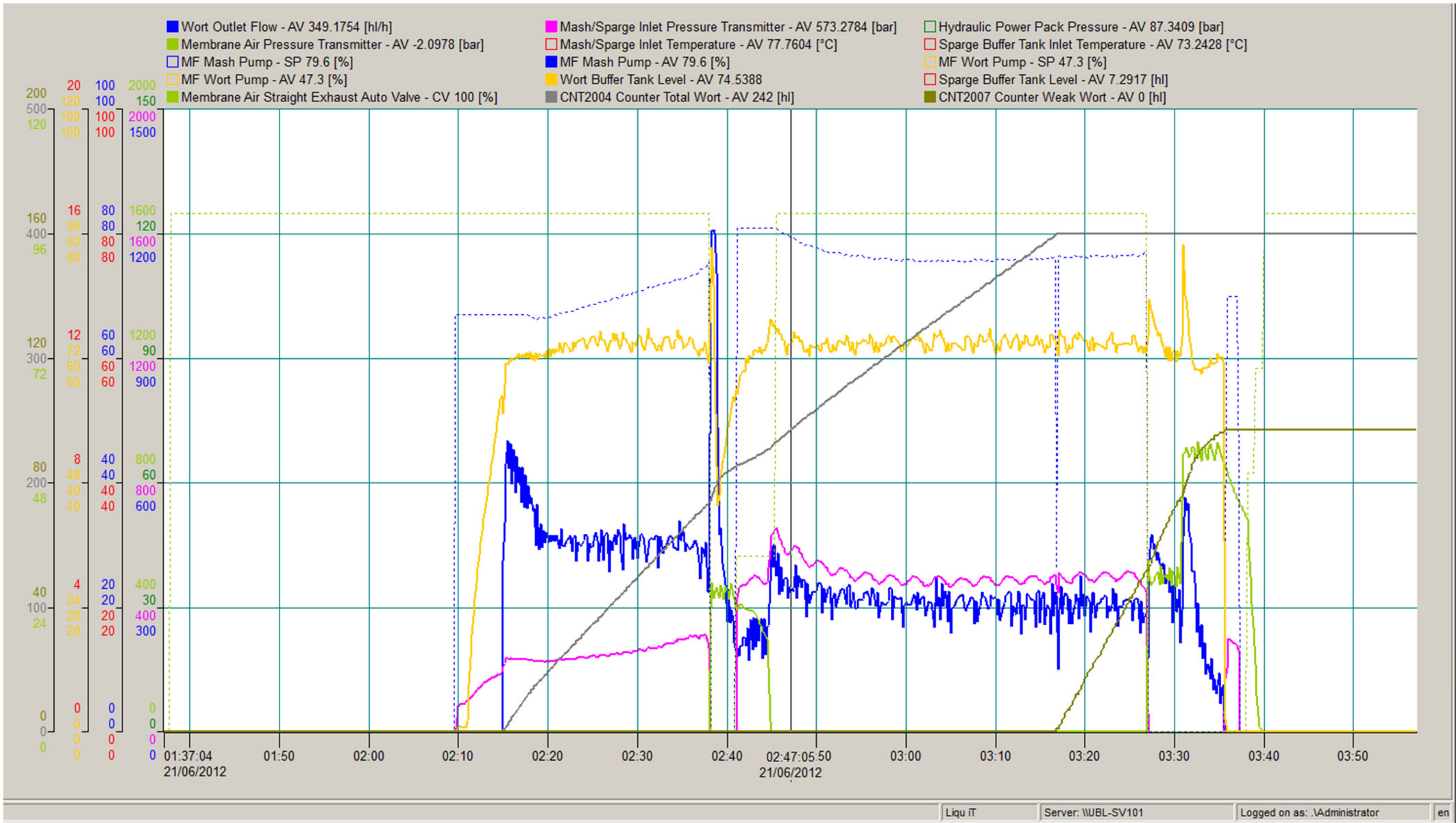
Mash Filter – *Meura 2001 Hybrid*

- Installation in Uganda –
  - 102 hybrid chambers
  - 7 to 10.2 Te grist
  - 320 to 400 hl cold wort
  - 10 BPD initially
  - 12 BPD future



- Mash Filter Capability –
  - Up to 14 BPD
  - High extract yield
  - Up to 100% adjunct
  - Minimal effluent
  - Drier spent grains
  - Limited flexibility

Mash Filter – Operation (*Meura 2001 Hybrid*)



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Mash Separation - Comparison

	Mash Tun	Lauter Tun	Mash Filter
Throughput	Low ≤ 4 b.p.d.	Mod. – High 8 to 12 BPD	High 12 to 14 BPD
Extract Efficiency	OK 95 to 97%	Good 98 to 99%	High >100 %
Flexibility	Good 30 to 100%	Good 40 to 100%	Poor 80 to 110%
CIP	OK	OK	Inefficient 4 to 8 hrs
Complexity	Simple	Complex	Complex
Cost	Low	Moderate	High

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Wort Pre-Heating – Temperature raise

- Energy Input
- $q = M \times C_P \times (T_2 - T_1)$
  - M = Mass (kg)
  - C_P = specific heat (kJ/kg C)
  - T_1 & T_2 = Initial & Final Temperature (°C)
- Example - Heat 1000 hl wort (1.06 SG) from 75 to 100 °C
  - Density = 1.06 x 97.4 kg/hl = 103.2 kg/hl
  - Mass M = 1000 hl x 103.2 kg/L = 103,200 kg
  - Specific Heat C_P kJ/kg K
    - Energy to heat 1 kg by 1 °C (or °K)
    - Water = 4.2 kJ/kg K
    - Wort = 4.0 kJ/kg K
  - = 103,200 x 4.0 x (100 – 75) = 10,320,000 kJ = 10,320 MJ

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Wort Boiling – Evaporation phase change

- Liquid to Vapour – Energy Intensive
- Specific heat of Evaporation – h_{fg}
  - Energy to evaporate 1 kg
  - Water - h_{fg} = 2257 kJ/kg at atm pressure

- Boil Energy input
  - e.g. 5% volume off 1000 hl wort

  = M_E x h_{fg} M_E = Mass Water Evaporated

    - M_E = 1000 hl x (5/100) x 100 kg/L = 5,000 kg

  = 5,000 kg x 2257 kJ/kg = 11,285,000 kJ

  =11,285 MJ

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Wort Boiling - Objectives

Objective	Process Factors
Volatile Removal	Evaporation & Turbulence
Isomerisation	Temperature & Time
Flocculation	Vigorous Boil (Wort/vapour interface - bubbles), Low Shear
Sterilisation & Enzyme Inactivation	Temperature & Time
Gravity / Volume	Evaporation

Evaporation itself is not the key process in Wort Boiling,
Other factors are more critical.

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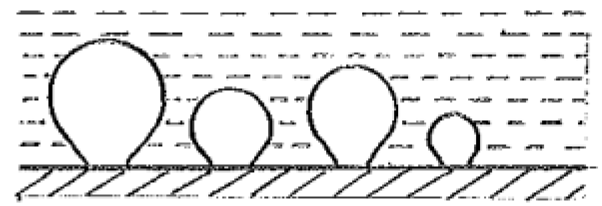
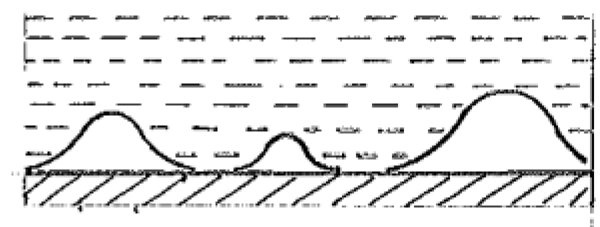
Wort Boiling – Heating surface

- Boiling Mode affected by –
  - Temperature Difference
  - Surface 'Wettability'
- Copper
  - 'Wettable'
  - Vapour bubbles easily released
  - Film boiling only at very high ΔT
- Stainless Steel
  - Non-Wettable
  - Vapour clings to surface
  - Film boiling can occur at low ΔT



COPPER – 'WETTABLE'

Vapour Bubbles released



STAINLESS STEEL –

'NON-WETTABLE'

Vapour bubbles cling to surface.

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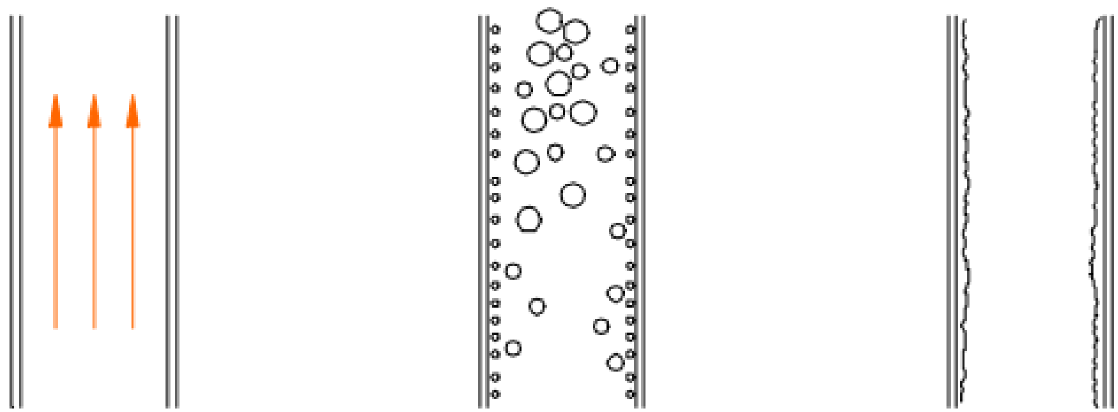
Wort Boiling – Heat Transfer Modes



FORCED CONVECTION

TURBULENCE THROUGH HIGH LIQUID VELOCITY

LOW ΔT
OR HIGH BACK PRESSURE
HIGH FLOWRATE AND/OR
MULTI PASS HEAT EXCHANGE

NUCLEATE BOILING

TURBULENCE THROUGH BUBBLING & TWO PHASE FLOW

MODERATE ΔT
'WETTABLE' SURFACE
MINIMAL BACK PRESSURE

FILM BOILING

LAMINAR VAPOUR FILM BLANKETS SURFACE

HIGH ΔT
'NON-WETTABLE' SURFACE
RAPID FOULING

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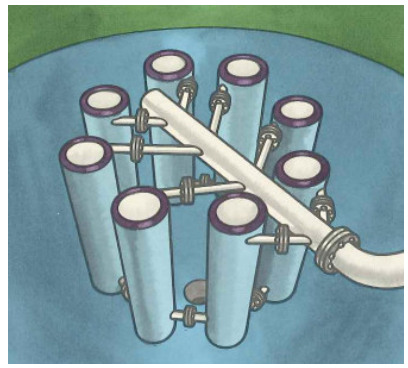
Boiling Heat Transfer - Fouling, Area & ΔT

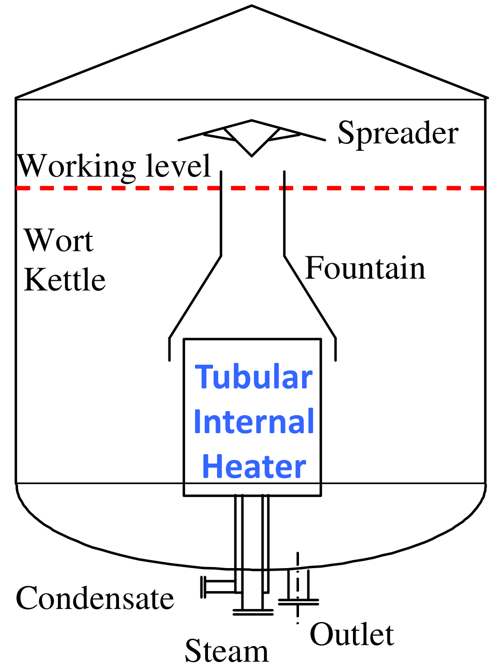
- $Q = U \times A \times \Delta T$
  - U – Heat Transfer Coefficient
    - Higher for Nucleate Boiling
    - Low for Film Boiling
    - Fouling reduces U progressively
  - A – Surface Area
    - Low Surface Area needs higher ΔT
  - ΔT – Temperature Difference – Driving Force
    - Low ΔT needs Large Surface Area
    - Low ΔT reduces fouling

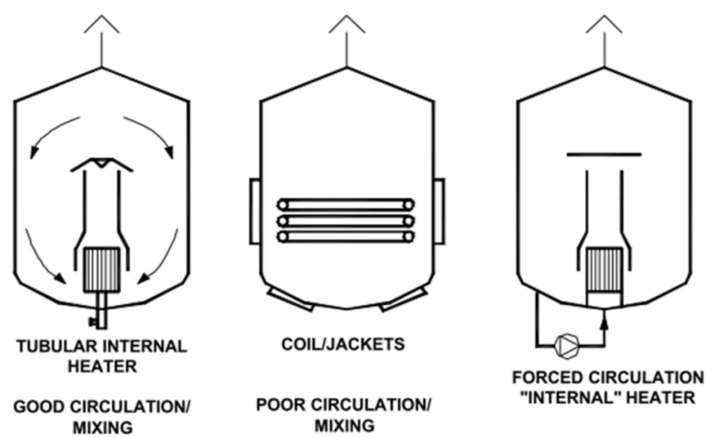
Wort Boiling - Internal Wort Heater

- Traditional
  - e.g. North America
- Percolators
  - Very low Surface area
- Tubular Internal Heater
  - Low Surface Area
    - Typically 0.08 m²/hl
- Needs frequent CIP
- Fountain & Spreader
- May be pump assisted
  - Similar to External Heater



Percolator





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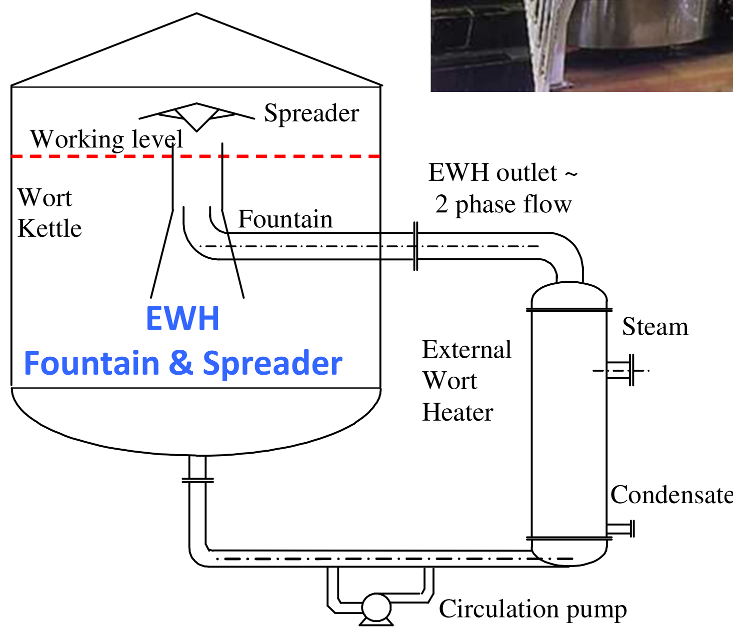
Wort Boiling – External Wort Heater

- Flexible
  - Brewlength
  - CIP volume
- Fountain & Spreader
- Thermosyphon
  - low shear
  - Typically 0.2 m^2/hl

OR

- Forced Circulation
  - Pumped
  - high shear



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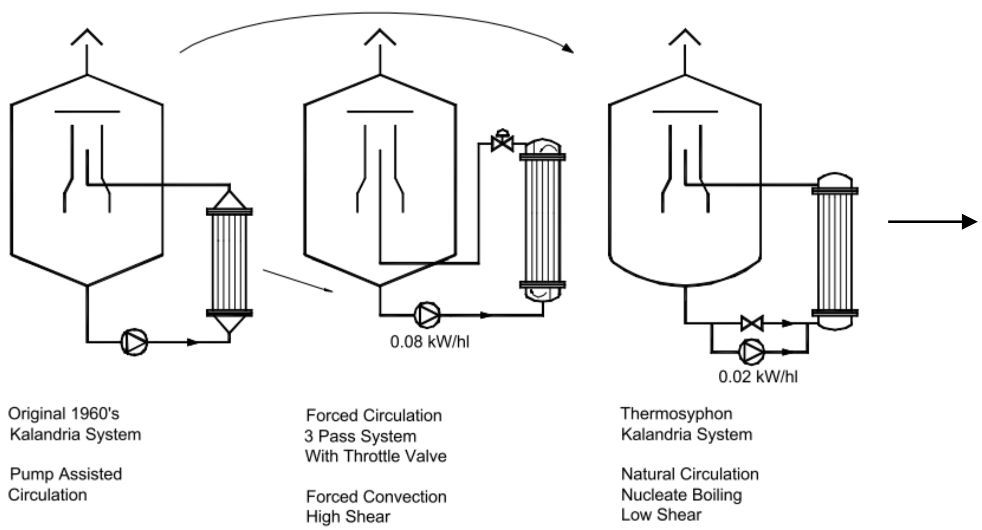
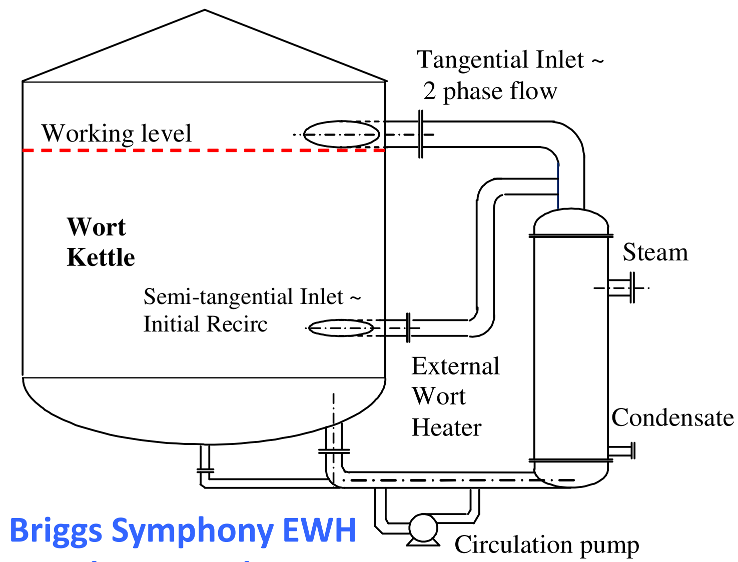
External Wort Heating Development





Pump Assisted
Short tube

Short Tubular heater.

Low surface area.

Axial flow pump.

CIP 10 to 12 brews.

Forced Circulation
Long tube

Long Tubular heater.

Higher surface area.

Centrifugal high flow pump.

Back pressure, restricted outlet

Natural Circulation
Thermosyphon
Long tube

Long Tubular heater.

Higher surface area.

Large outlet.

Natural circulation during boil.

Briggs Symphony EWH
Thermosyphon

- Tangential Inlet
  - Low Shear
  - No internals
- Boil on the whirl
  - Improved Mixing
  - Low level inlet – reduced foam
- 2 Phase flow – high level inlet
  - Vapour / Liquid interface
  - Volatile Stripping
- EWH – High Surface Area
  - Vapour bubble formation

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Wort Boiling – Energy Recovery

- Wort Boiling - Major Energy User
- Minimise Evaporation
  - Maintain Wort Quality
  - 1 % reduction in evaporation
    - saves approximately 2 to 4% of Brewhouse energy consumption (1 to 2% of total brewery energy consumption)
    - Reduces peak steam / HTHW loads
    - Reduces emissions
- Energy - Recycle or Recovery
  - MVR – *Recycle over 90% of energy during boil*
  - TVR – *Recycle up to 50% of energy during boil*
  - Energy Store – *Recover energy for use elsewhere*
    - Wort Pre-heating

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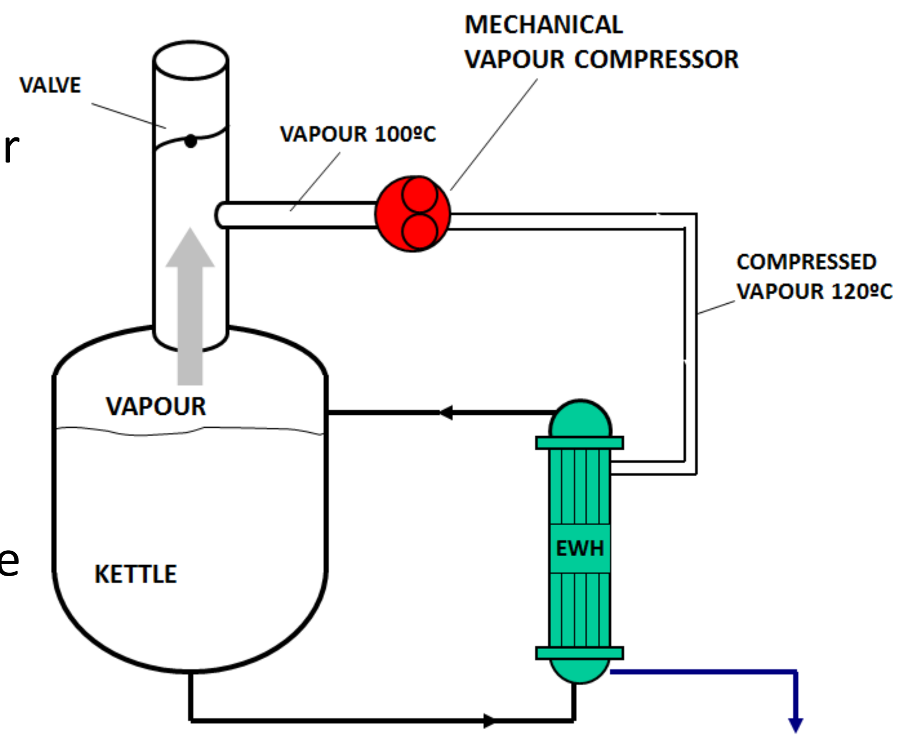
MVR – Mechanical Vapour Compression

- Direct Recycling of Boil Energy
  - Minimal Thermal Boil Energy Requirement
- Replaced with smaller Electrical Power Input
  - Electricity Requirement 0.1 - 0.7 kWh/hl
- High Capital Investment
  - Long Payback Period (>3 years)
- Large rotating machine – Maintenance
- Difficult to Maintain Air Free Wort Boiling
- Contaminated condensed vapour limits reuse



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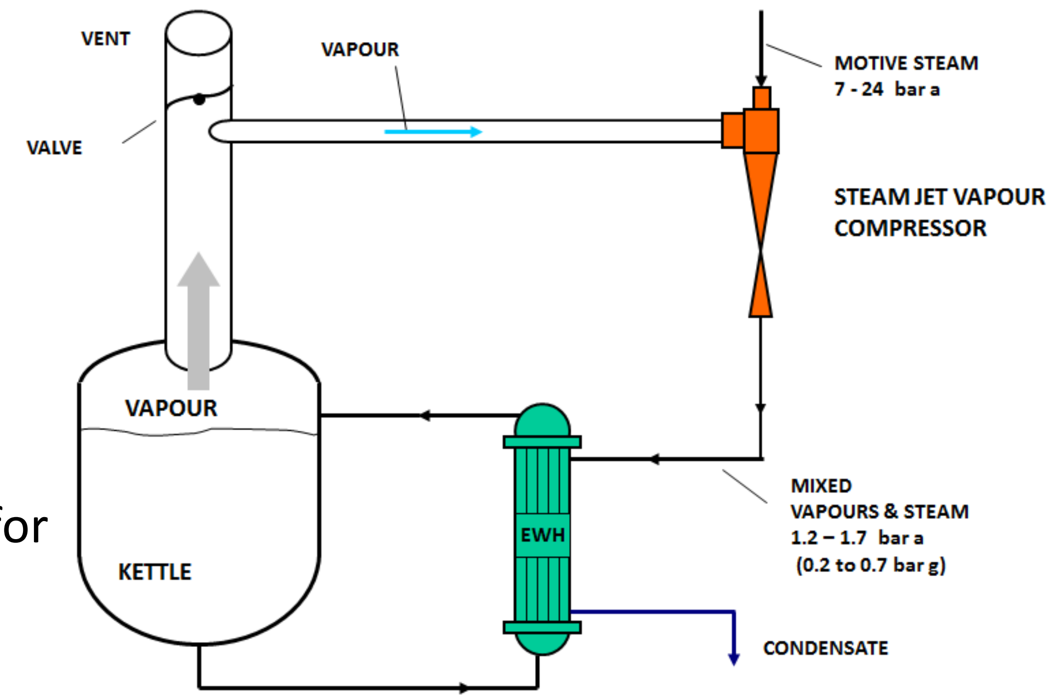
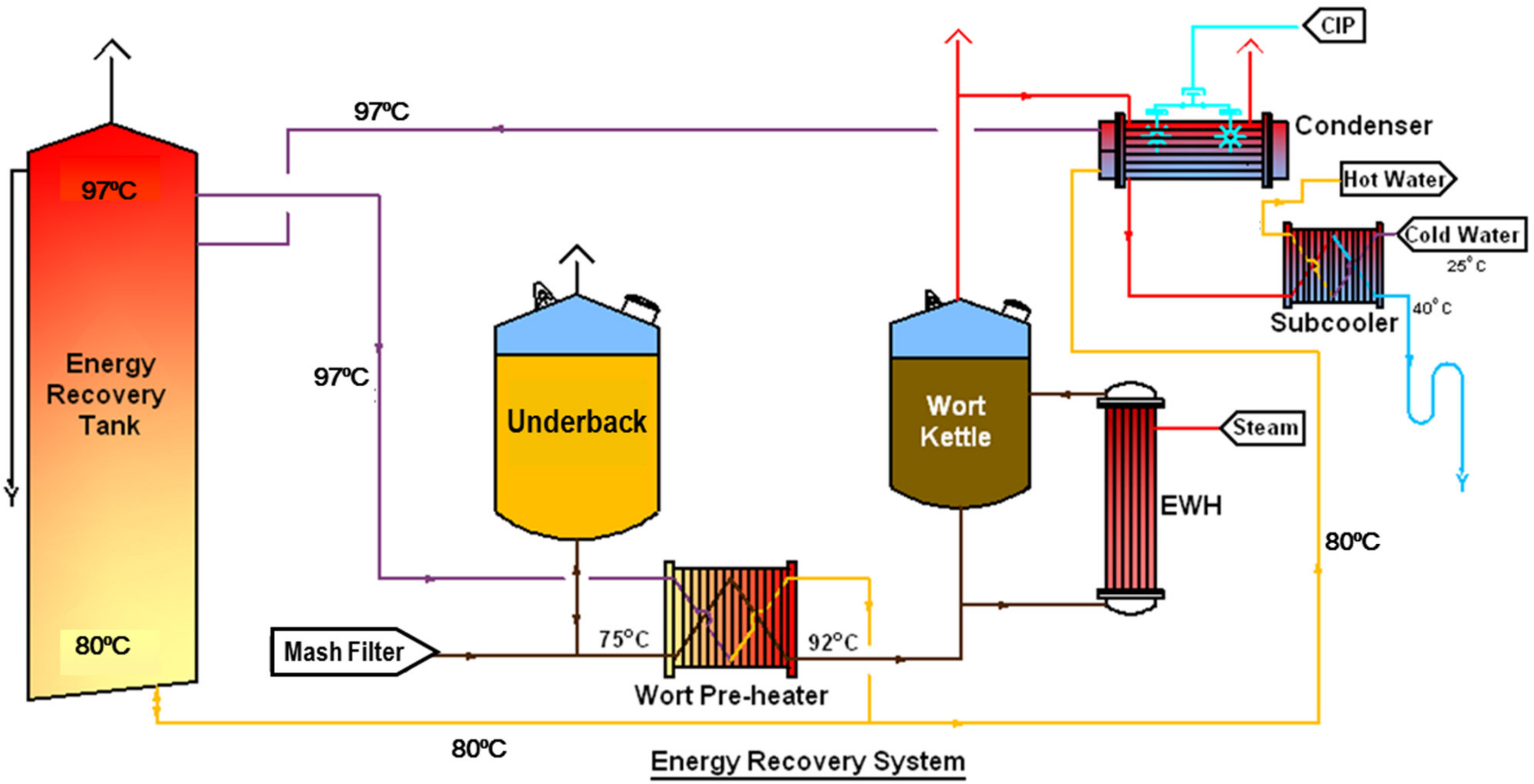
TVR – Thermal Vapour Compression

- Lower Capital cost than MVR
- Recycles 50% or less of boil thermal energy
  - Reduced Energy saving
  - Can be combined with Energy Store to increase recovery
    - Dual system – increased complexity & cost
- Requires high pressure steam for recompression
  - typically 10 bar g or higher
- Contaminated condensed vapour limits reuse



Energy Store – Wort Pre-heating



Energy Recovery - Wort Pre-Heating

- Heating Energy = M x C_P x (T_2 – T_1)
- No Energy Recovery
  - Heat 1000 hl wort – 75 to 100 °C

    = 100,000 x 4.0 x (100 – 75) = 10,000,000 kJ

    = 10,000 MJ
- With Wort Pre-heating to 92 °C
  - Heat 1000 hl wort – 92 to 100 °C

    = 100,000 x 4.0 x (100 – 92) = 3,200,000 kJ

    = 3,200 MJ
- Energy Saving = 10,000 MJ - 3,200 MJ = 6,800 MJ

  = 68% reduction

  Steam Saving = 6,800,000 kJ / 2,133 kJ/kg = 3,188 kg/brew

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Energy Store, Condenser & Pre-heater

Energy Store Tank

Condenser

Pre-heater

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Wort Cooling – Energy Optimisation

- Heating of Hot Brewing Water at Wort Cooling
    - Biggest single energy saver in the Brewhouse
    - Established and proven
- Seasonal water temperature variation & recipe variation
    - Variation / excess hot water volume, and / or temperature
- Single Stage Cooling with Blending of chilled and ambient water
    - System balanced / optimised
    - Closer approach temp - Refrigeration energy minimised
- Multi Stage Wort Cooling
    - 1 - Hot section with Energy Store – Heat energy source -> Wort Pre-heating
    - 2 – Wort / Ambient Brewing water -> Hot Brewing water
    - 3 – Wort / Chilled water or glycol - Cold Energy buffer
        - Buffering smooths peak loads
        - Alternatively direct primary refrigerant on final stage

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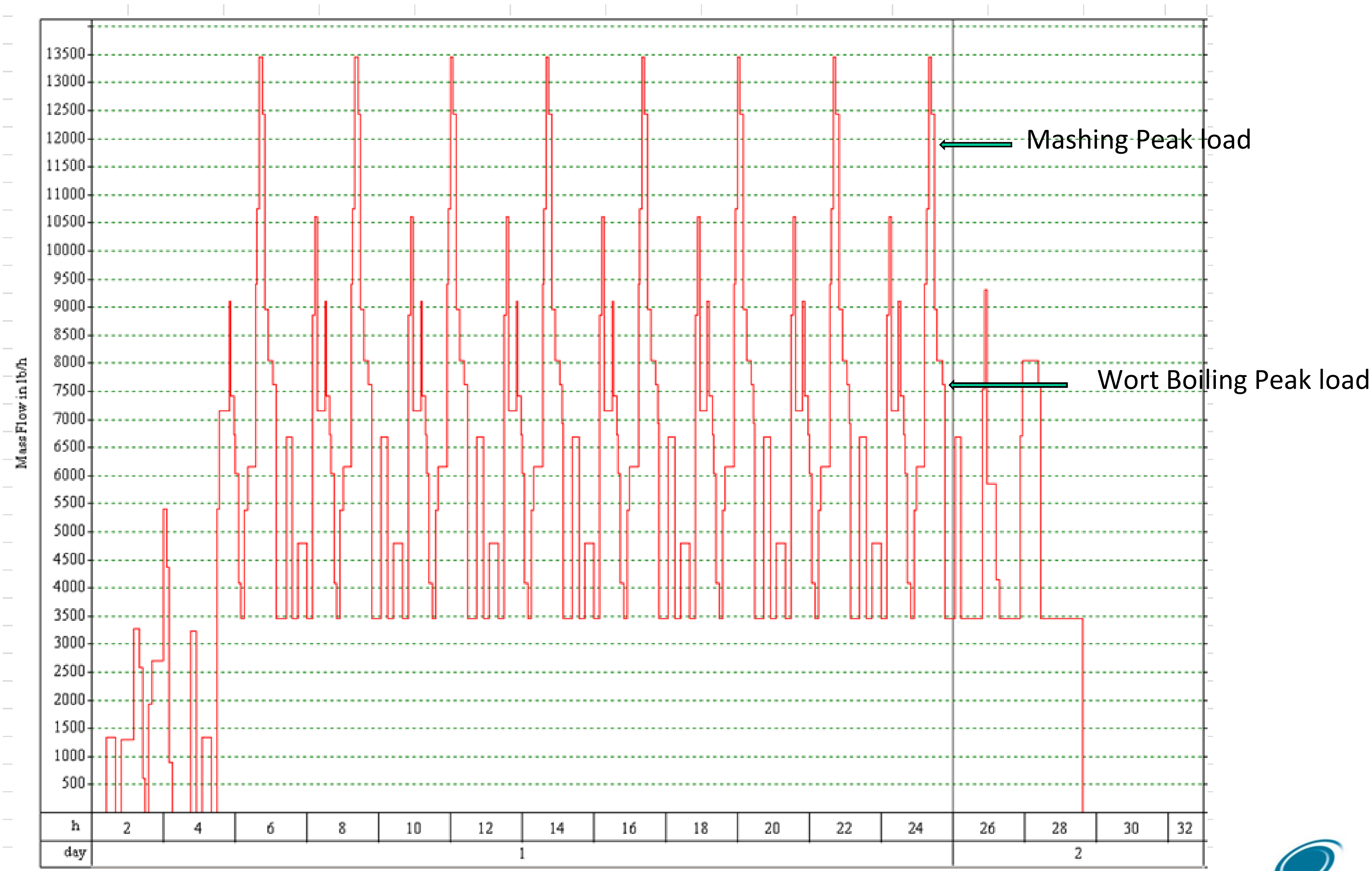
Heat Energy Provision & Balancing



Short TAT Brewhouse

- More brews/day x Smaller Brewlength
- Lower peak / smoother utility loads
- Smaller physical size – shorter runs
- Reduced energy loss

Brews/Day	Brewlength hl	Volume / Day hl/day
14	200	2800
10	280	2800
8	350	2800

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Continuous Brewhouse

- Comparison -
  - Batch –
    - 200 hl x 14 BPD
    - 350 hl x 8 BPD
  - Continuous – 100 hl/h
- Small plant size – 60% vs 14 BPD
- Reduced losses & energy consumption
- Smooth utility load – minimal peaks

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Pump Selection

- Pumps consume 10% of world electrical energy
- Power is typically 85% of a pumps total cost of ownership
- Pump Efficiency = $\frac{\text{Power Imparted on Fluid}}{\text{Power Supplied to Drive}}$
- Pump Efficiency –
  - High efficiency at duty point = Low power use
  - Low efficiency at duty point = High power use (& higher shear)
- Case Study: Pump Duty = 12m^3/hr at 39m head
  - – Pump A: Low capital cost
  - – Pump B: Higher efficiency

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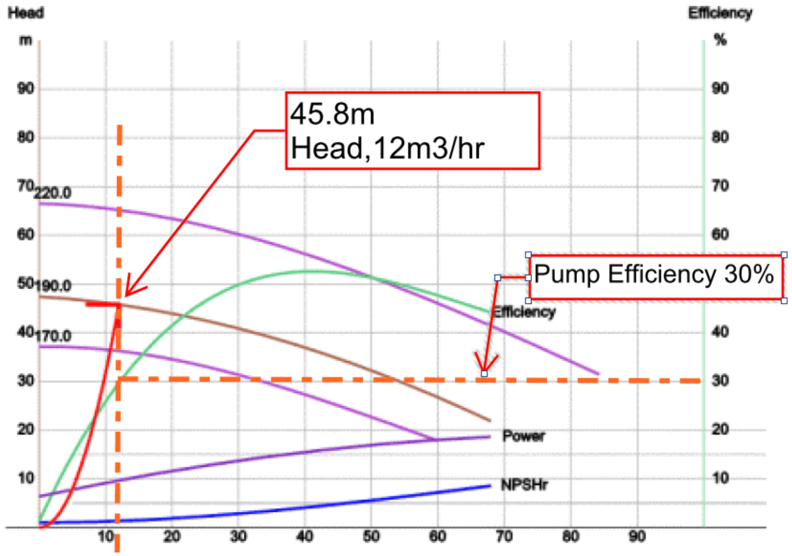
Pump - Capital Cost vs Efficiency

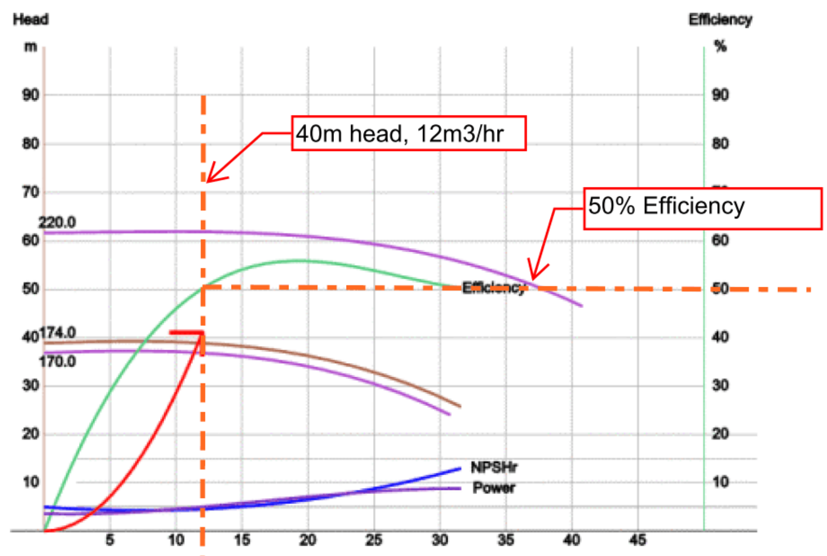


Low Capital Cost & Efficiency

This pump could achieve 50% + efficiency, but not at duty point. Low efficiency at duty, high power usage & running costs.

Higher Capital Cost & Efficiency

This pump has duty point closer to maximum efficiency.
Higher efficiency & lower operating costs.
In reality efficiency could be higher, typically 60 to 70%.



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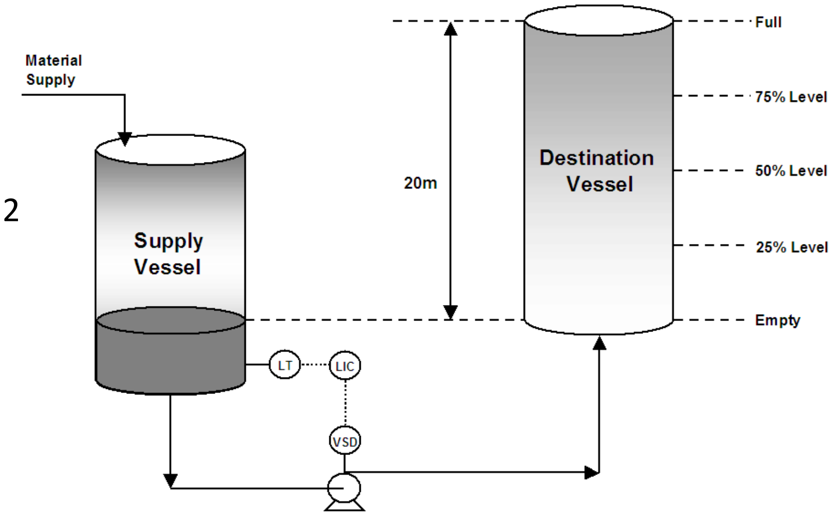
VSD Pump Operation

- In reality pumps often have a range of duties.
- Example – filling a tank at constant flow and variable level
- Pump Affinity Laws
  - Flow proportional to (speed)
  - Head (pressure)proportional to $(speed)^2$
  - Power is proportional to $(speed)^3$



- Pump Speed 50%
  Power Consumption 12.5%
- Using pump affinity laws we can estimate the pump speed & power used to maintain flow as the level in the tank increases

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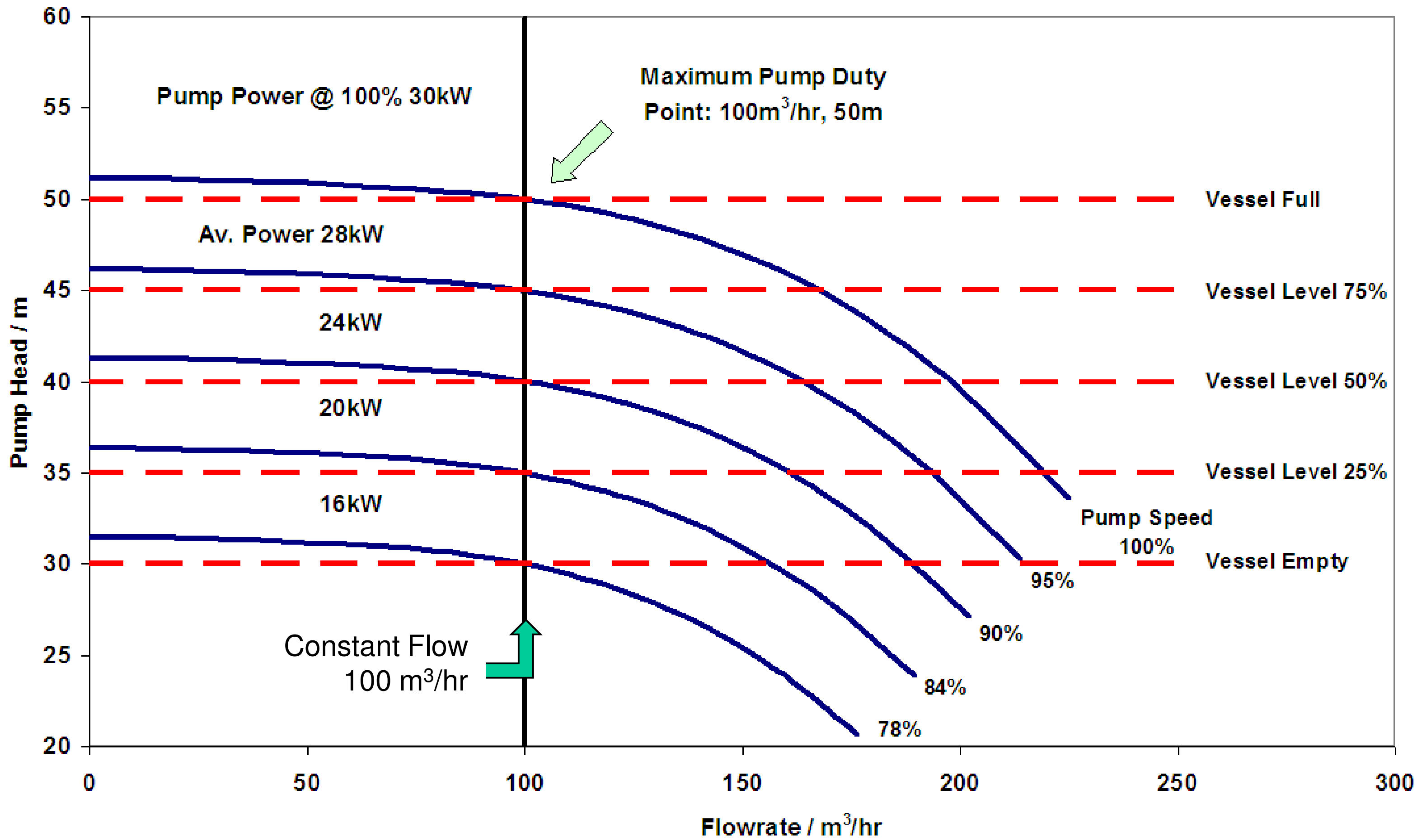
VSD Pump Curve

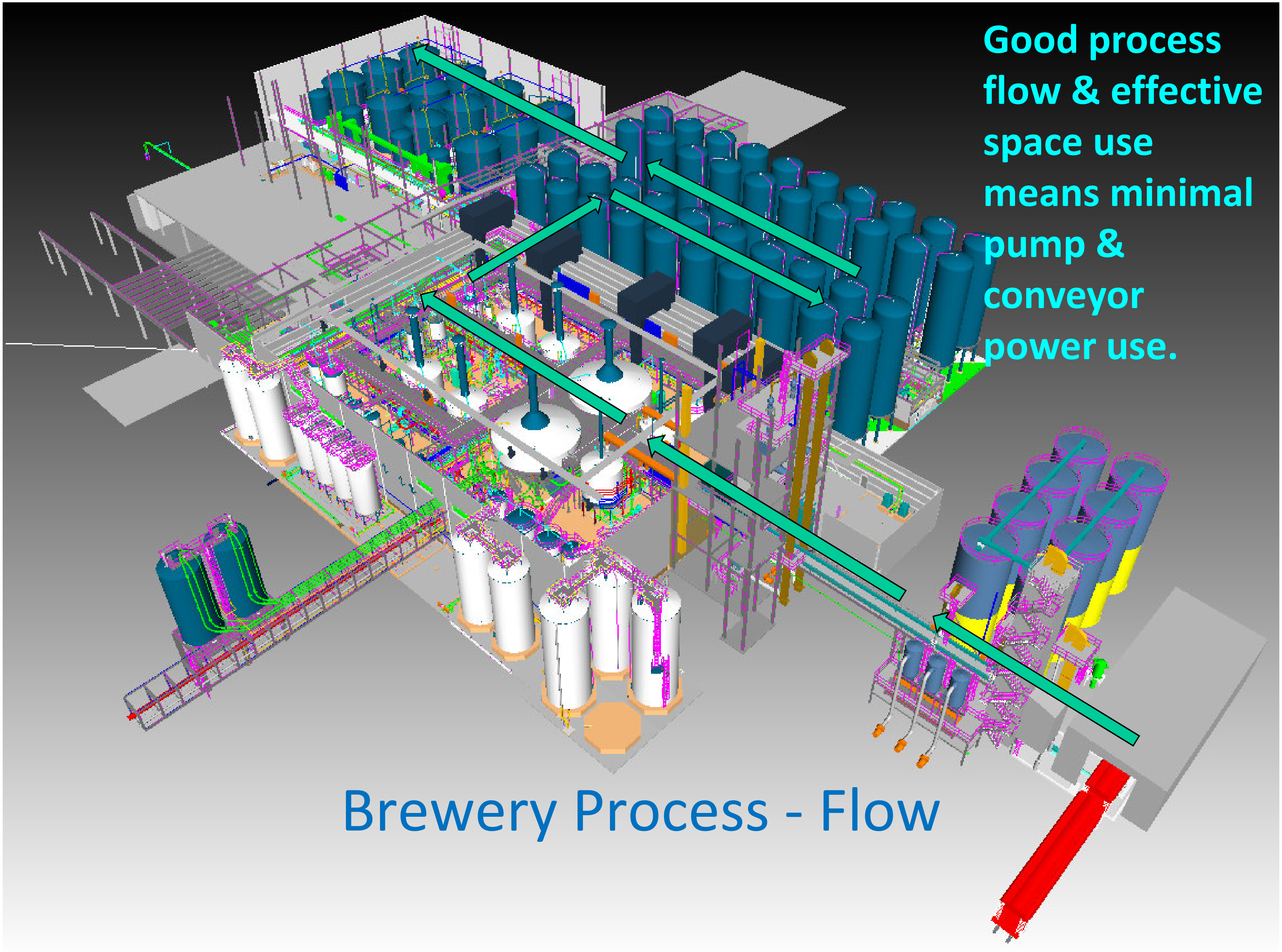


VSD Pumps – Power Use

Tank Level	Pump Speed	Power Consumption
Empty	78%	14 kW
25%	84%	18 kW
50%	90%	22 kW
75%	95%	26 kW
Full	100%	30 kW

- Daily Energy Consumption
  - Fixed Speed 720 kWh
  - VSD <u>526 kWh</u>
- Energy Consumption Reduction <u>26%</u>

BRIGGS


Good process flow & effective space use means minimal pump & conveyor power use.
Brewery Process - Flow