Brewery Sustainability and Energy Integration

Brewing Engineers Association Technical Day

Brewing Engineering & Services for Efficiency

National Brewery Centre, Burton-on-Trent

March 2017

John Hancock – Briggs of Burton

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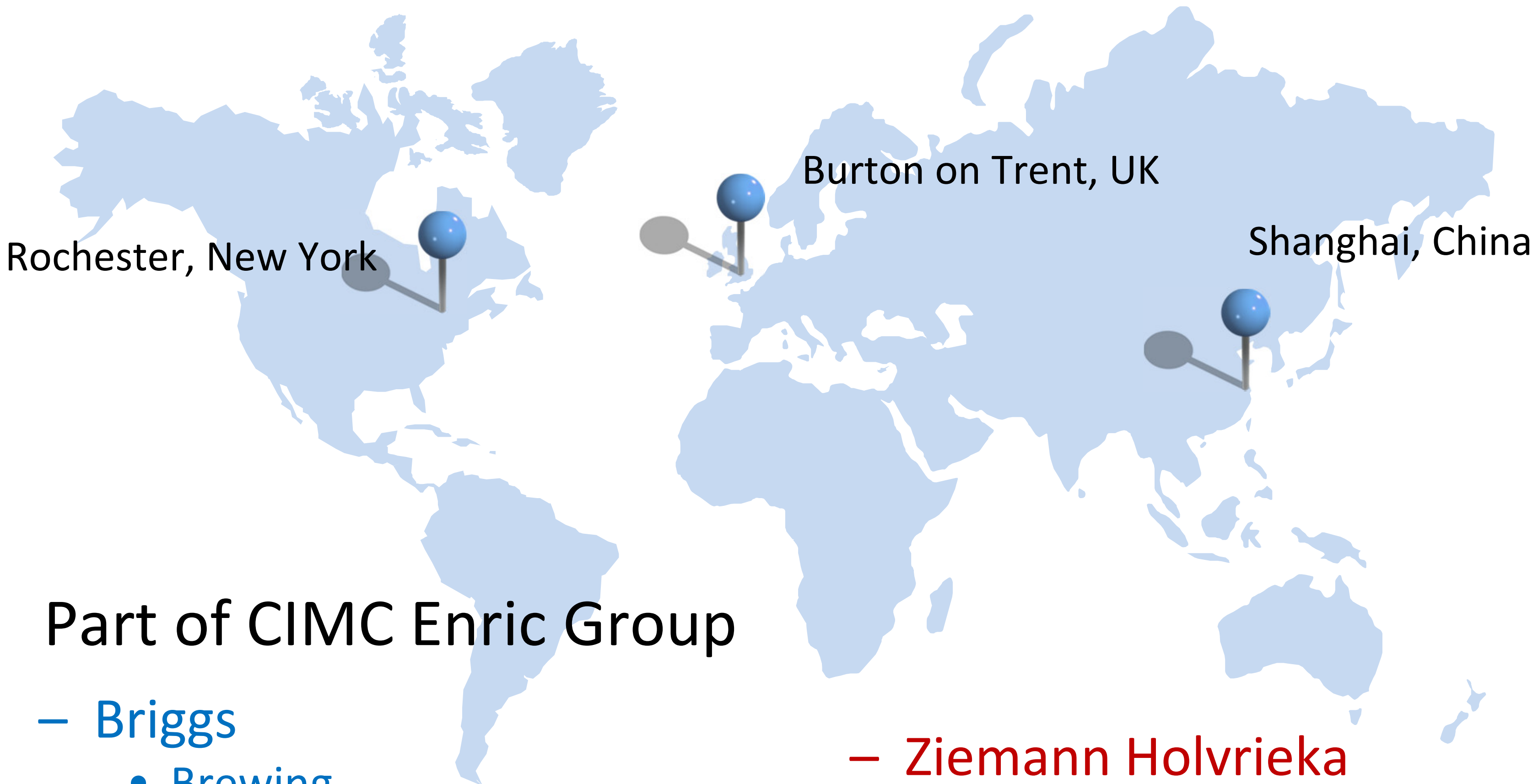

Part of CIMC Enric Group

– Briggs
  - Brewing
  - Distilled Spirits
  - Biofuel
  - Food
  - Pharmaceutical

– Ziemann Holvrieka
  - Brewing
  - Dairy and Juice
  - Chemicals

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Sectors

- Biofuel
- Brewing
- Distilling
- Material Handling
- Food
- Health and Beauty
- Pharmaceutical

Capabilities

- Project Management
- Process Engineering
- Automation and Control
- Electrical Engineering
- Manufacturing
- Concept / FEED Studies
- Value Engineering
- Detailed Design
- Project Implementation
- CDM + Health & Safety
- EPC / EPCM / Hybrid

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Brewery Sustainability and Energy Integration

- Brewhouse Process
  - Mash Conversion & Heating
  - Mash Separation
  - Wort Pre-heating, Boiling and Energy Recovery
  - Wort Cooling optimisation
  - Heat Energy provision and balancing

- Brewery Cold Process
  - Technology review for key process steps
  - Identification of refrigeration duties & reasons to chill
  - Integration of Process & Refrigeration
- Pumps / Pipework –
  - Selection & Efficiency
  - VSD operation

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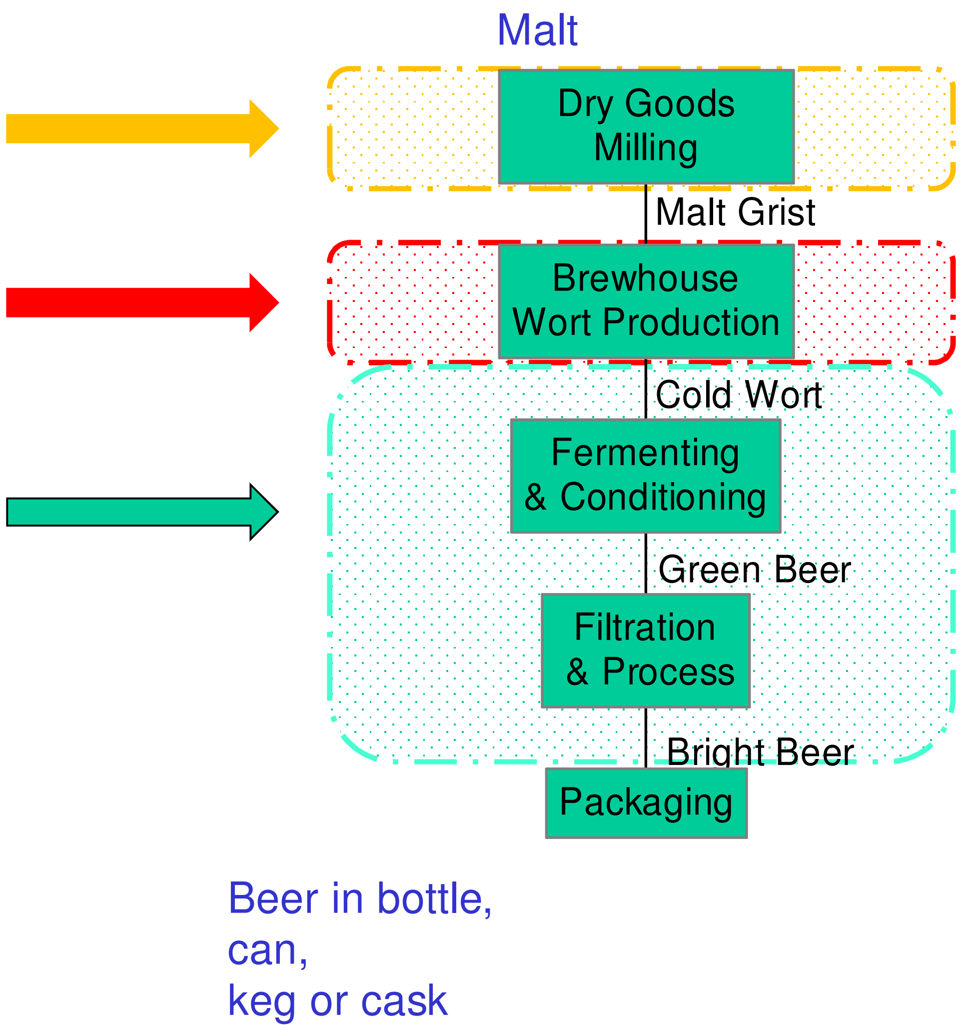
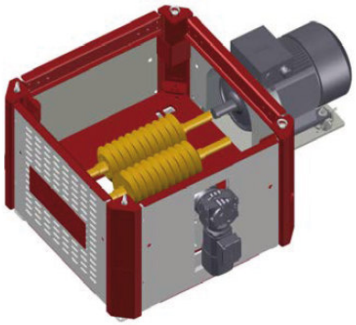
Brewery Process Flow

- Dry Process
  - Milling
- Hot Process
  - Brewhouse
- Cold Process
  - Fermenting & Conditioning
  - Filtration & Process



Raw Materials Handling
Milling Technology

- Roller Mill
  - Coarse MT / LT grist
  - Lower power use (2.9 kWh/Te)
  - Flexible & controllable
- Hammer Mill
  - Fine MF grist
  - High power use (6 kWh/Te)
  - Inflexible
- Steep Conditioned Roller Mill
  - Coarse MT / LT grist
  - Inflexible
  - Inability to sample
- T-Rex – Cracking Mill
  - Coarse or fine grist
  - Low power use (2.5 kWh/Te)



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Continuous Milling

- Can be used with continuous or Batch BH
- Lower capacity
  - typically 50 to 60% vs batch
- Smaller space usage
- Repeated start-up & shutdown eliminated
- Continuous low energy load
- Not suitable for recipes with multiple bulk malt types

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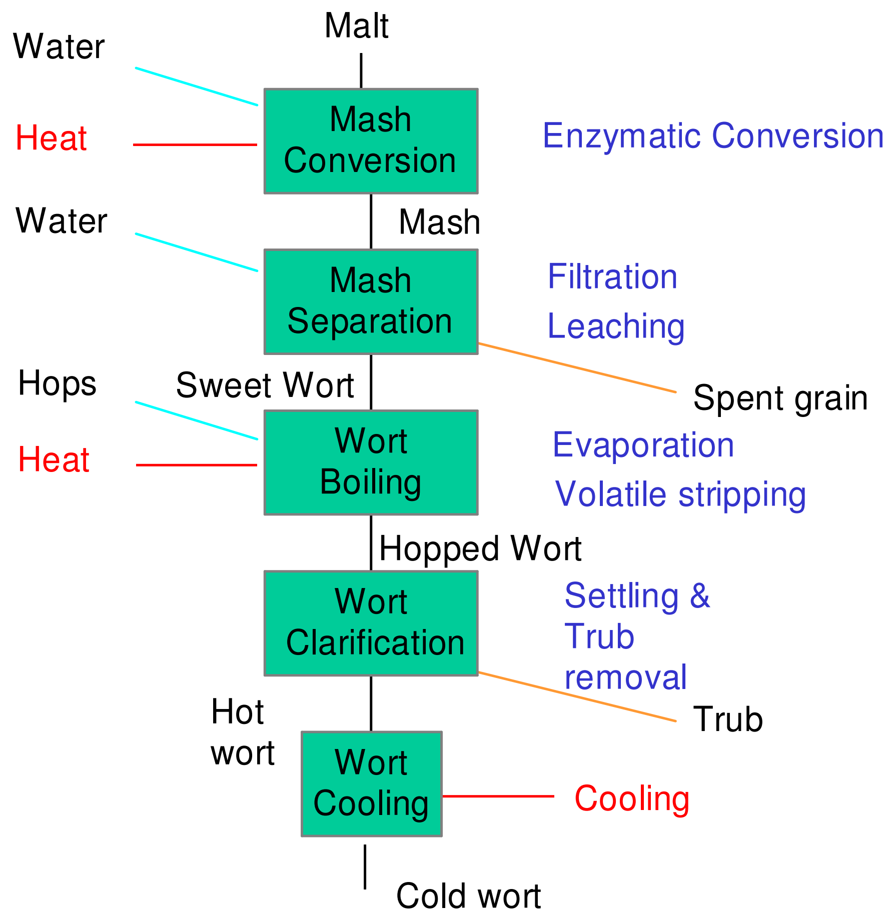
Brewhouse Process

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



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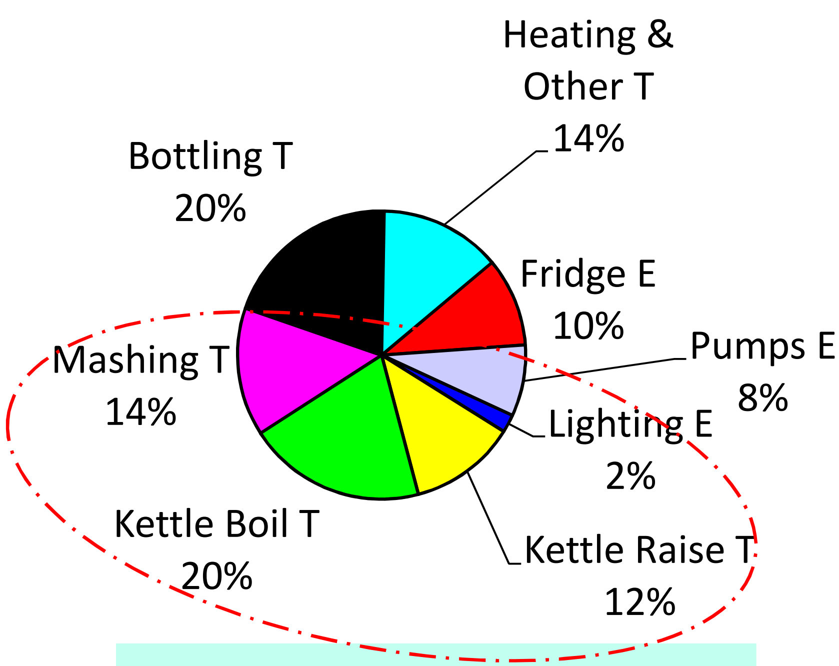
Brewery Energy Usage

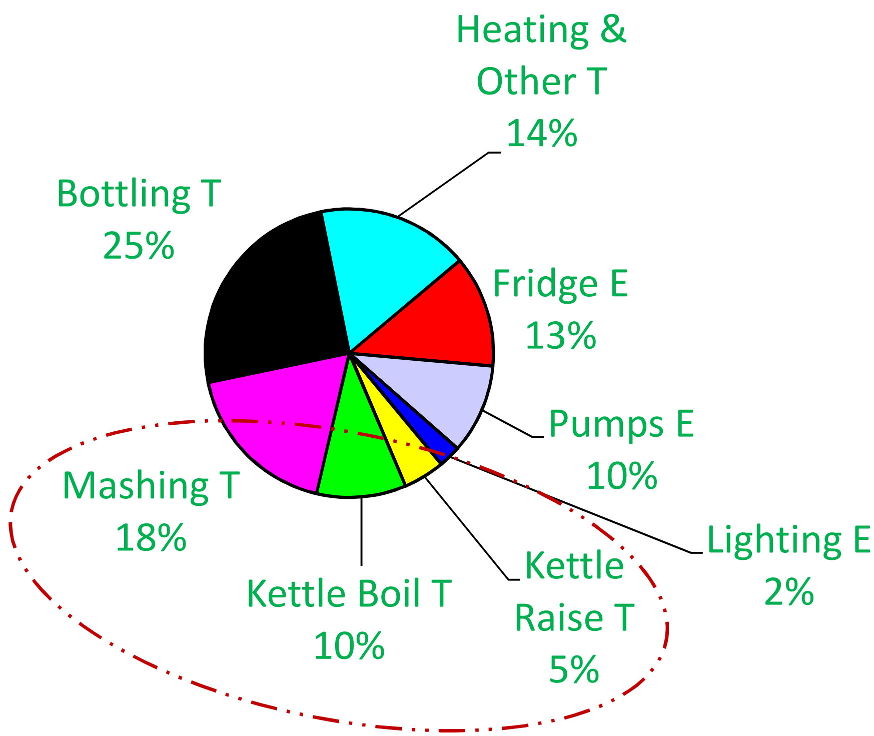
Brewhouse - Major Energy Users Mashing & Wort Boiling

<u>Historical data for a 10% Boil without Energy Recovery</u>



Beer Production - 125 MJ/hl

<u>Same Data with 4% Boil with Wort Preheating using Energy Recovery</u>



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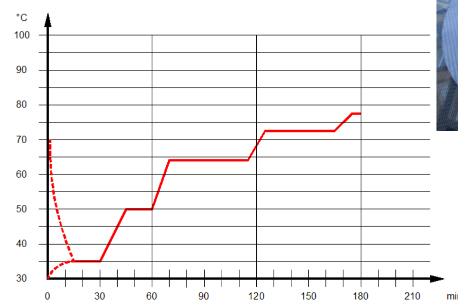
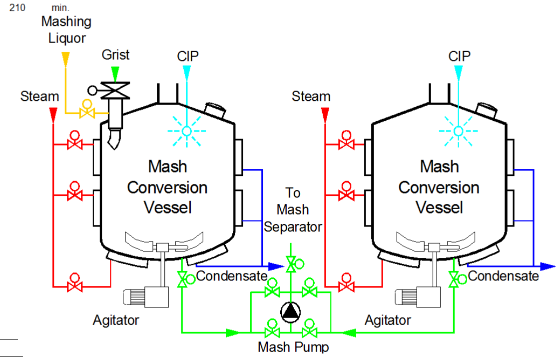
Mashing – Alternative Processes

- All Malt :
  - *Infusion Mash Tun or Distillery Mash Tun*
    - Combines Conversion & Separation
    - Minimal energy input

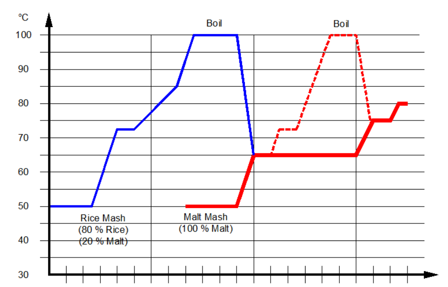
    or
  - Programmed Infusion – Mash Vessel
    - To feed separate Lauter Tun or Mash Filter
    - Mash in at around 65°C, lower energy input



  - 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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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
- Improved extract recovery with fine grist

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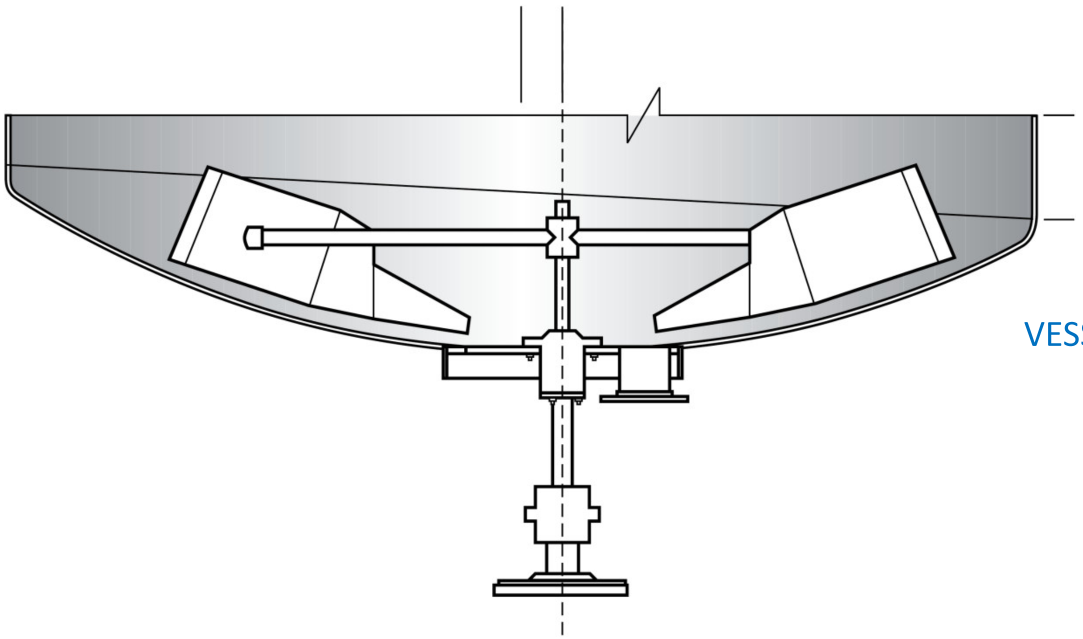
Mash Agitation - Minimising Mash Shear



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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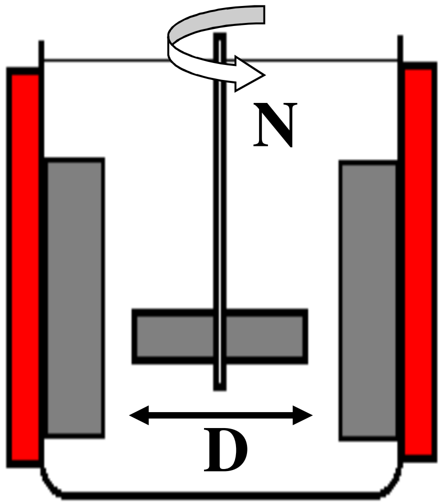
Mash Heating – Heat Transfer

- 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 Separation - Lauter Design
Maximise Extract Yield

- 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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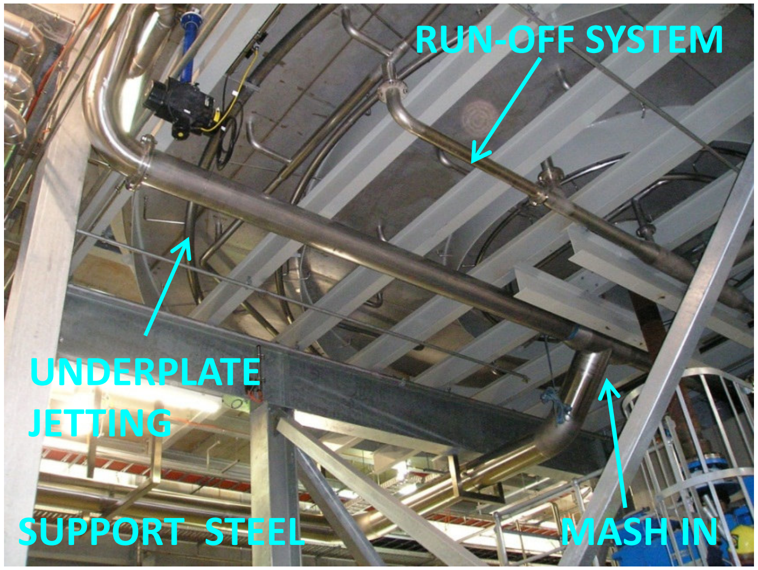
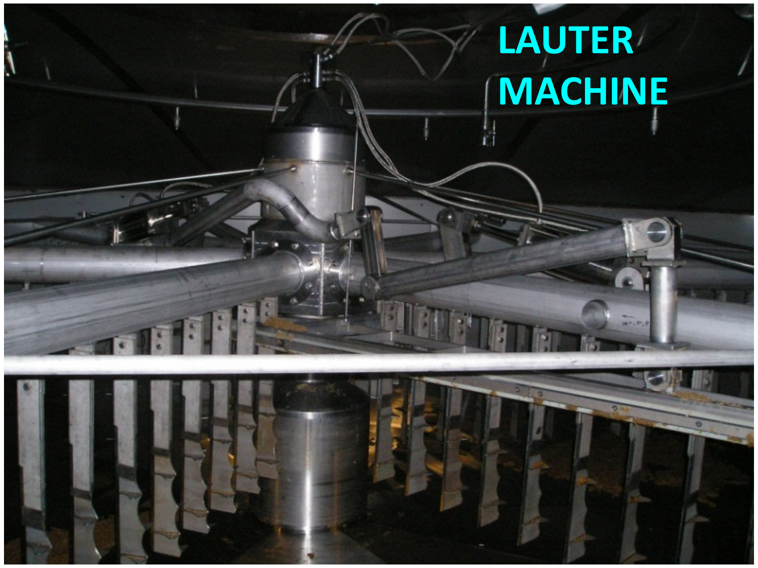
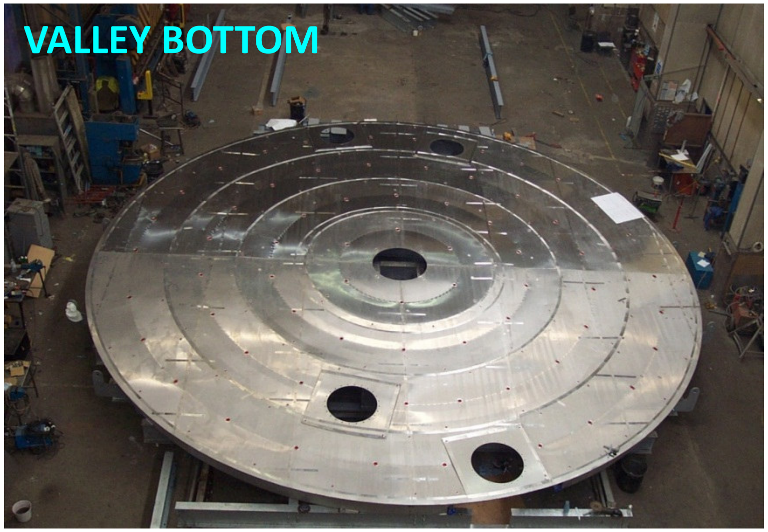
Lauter Tun







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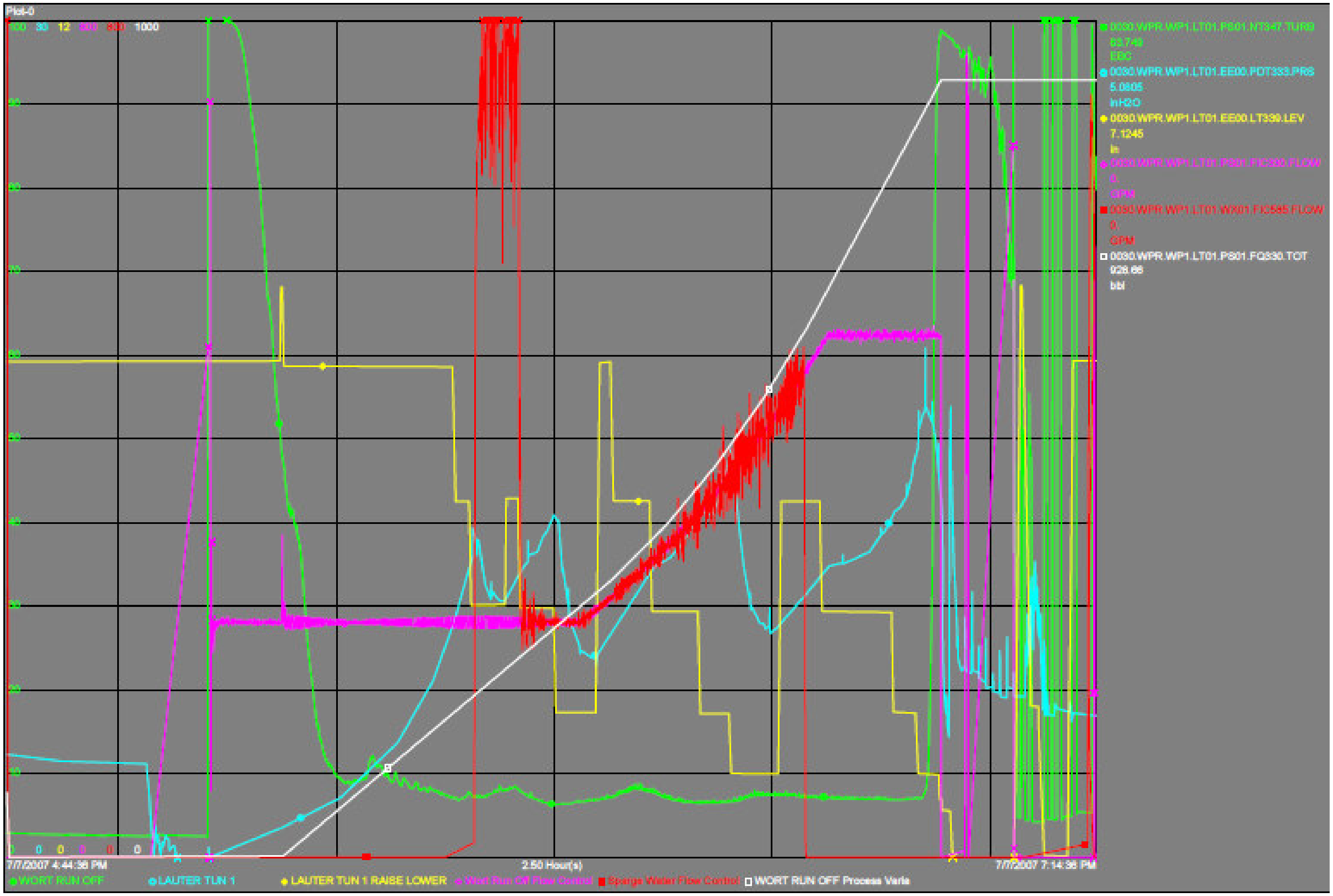
Brewery Lauter Tun Operation
12 Brews/Day at 160kg/m² - 12.8 m dia



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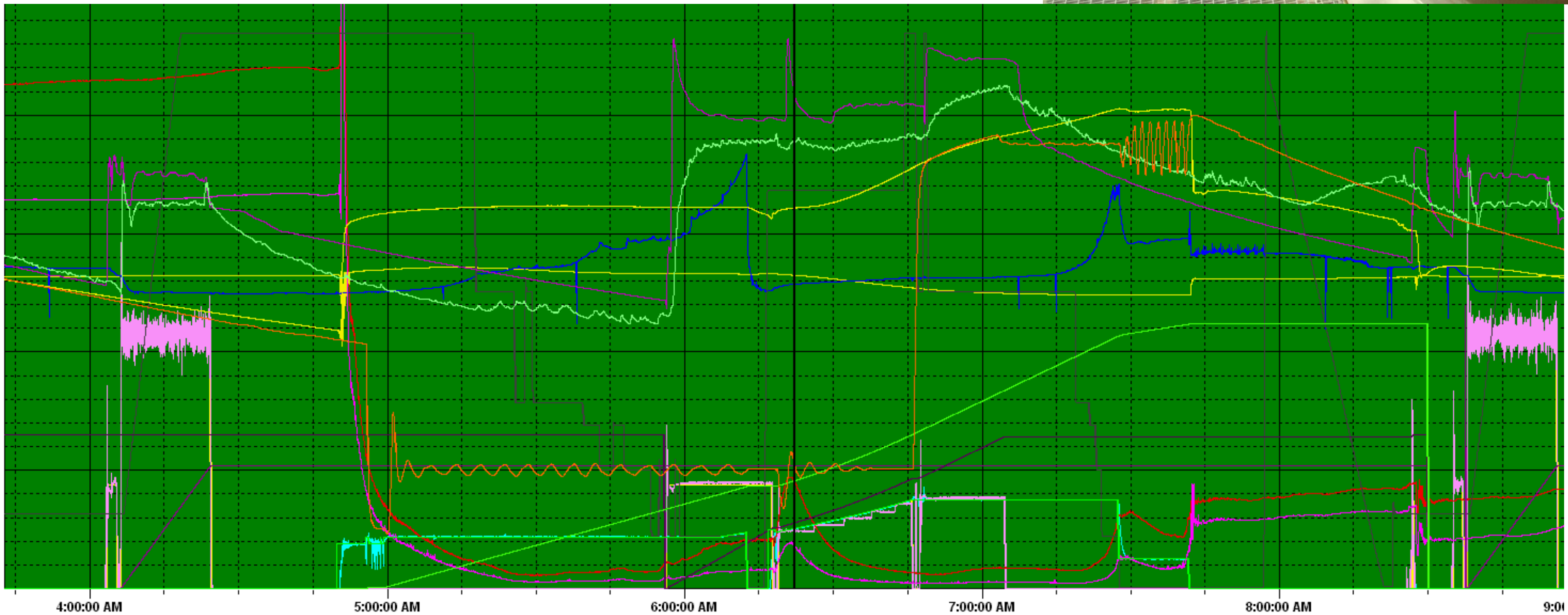
Distillery Lauter Tun

- Thin Mash – 4 L/kg
- Steeles Masher
- Conversion in Tun (stand)
- Large Weak Wort Volume
- -> Mash Water
- High final sparge temperature
- High Extract Recovery



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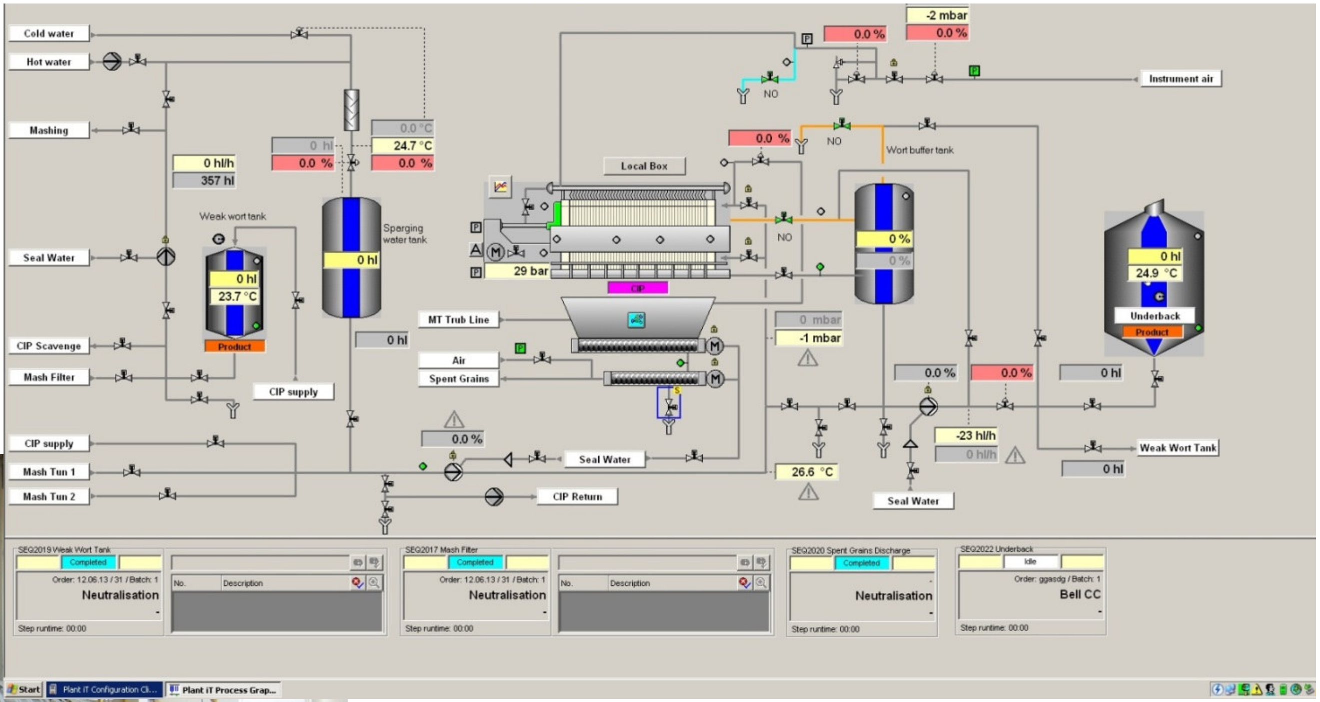
Mash Filter – *Meura 2001 Hybrid*

- 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

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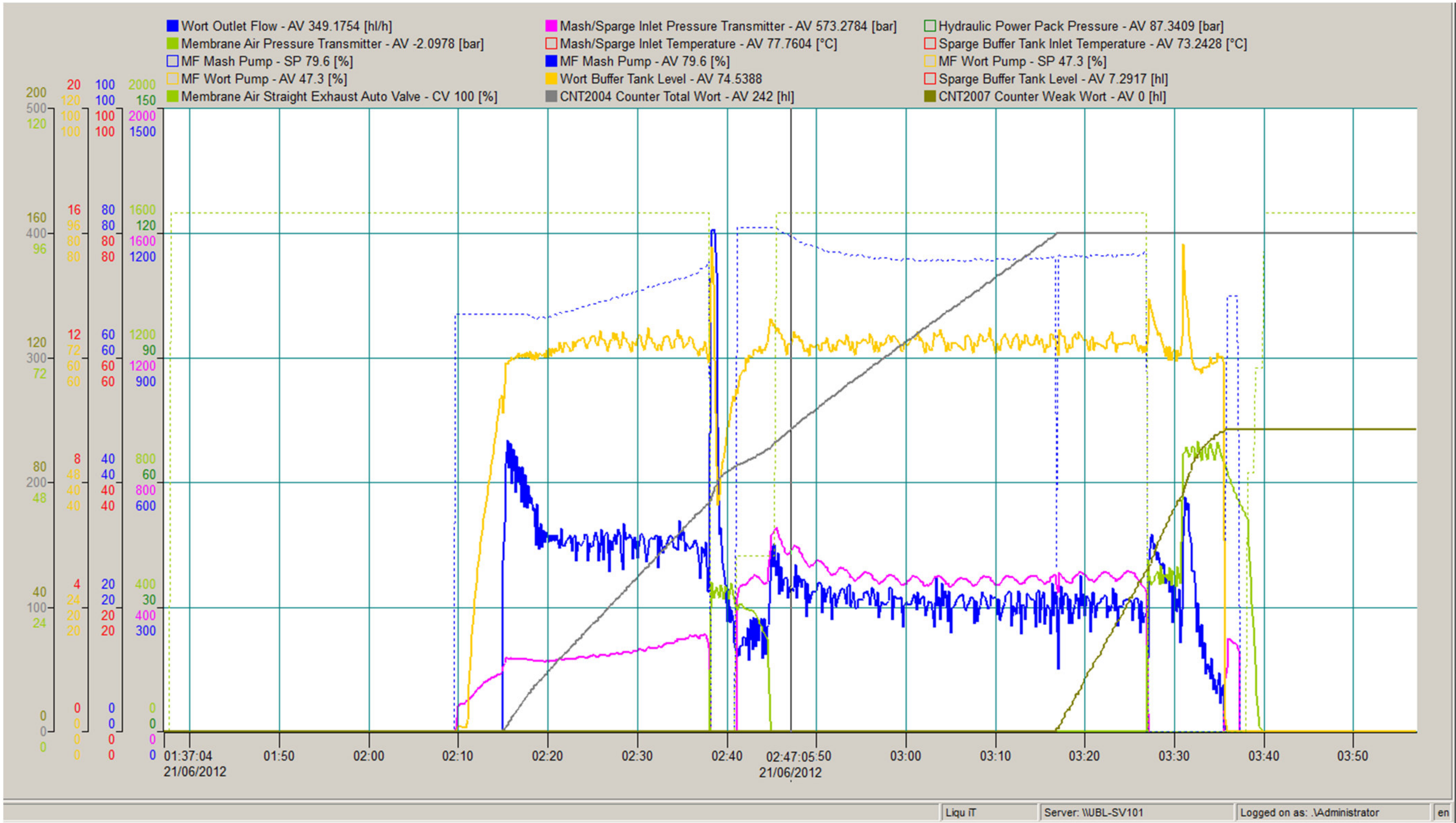
Mash Filter – Operation (*Meura 2001 Hybrid*)



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Mash Separation - Comparison

	Infusion Mash Tun	Distillery Full Lauter Tun	Brewery Lauter Tun	Mash Filter
Throughput BPD	Low ≤ 4 b.p.d.	4 to 7 BPD	Mod. – High 8 to 12 BPD	High 12 to 14 BPD
Extract Efficiency	OK 95 to 97%	High 99 to 101%	Good 98 to 99%	High >100 %
Capacity Flexibility	Good 30 to 100%	Good 40 to 100%	Good 40 to 100%	Poor 80 to 110%
Material Flexibility	Malt only	Malt only	Malt & up to 40% Adjuncts	Up to 100% Adjuncts
CIP	OK	OK	OK	Inefficient 4 to 8 hrs
Complexity	Simple	Complex	Complex	Complex
Cost	Low	Moderate	Moderate	High

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Wort Pre-Heating & Boiling - Energy

- **Pre-heat - 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)
- 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
      = 10.3 MJ/hl

- **Boiling**
- 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

  = $M_E \times h_{fg}$ 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

  =11.3 MJ/hl

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Wort Boiling – Objectives – Evaporation?

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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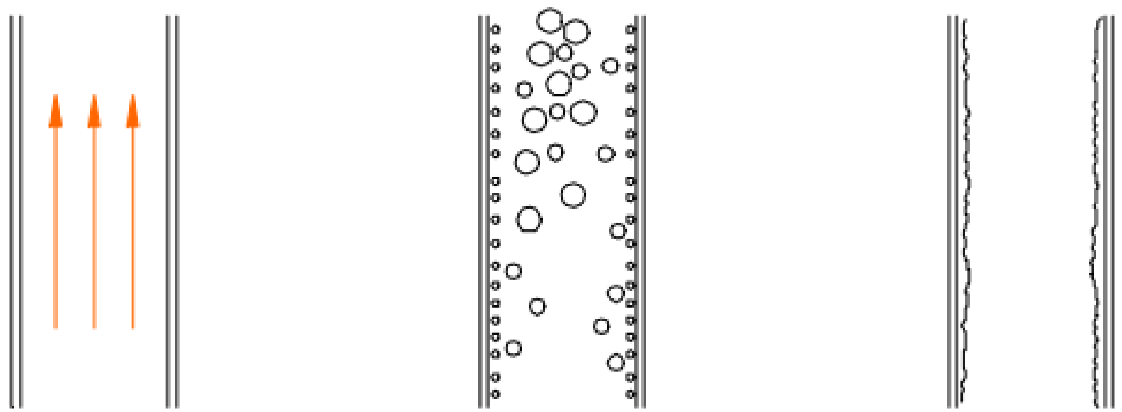
Wort Boiling – Heat Transfer Modes

FORCED CONVECTION	NUCLEATE BOILING	FILM BOILING



FORCED CONVECTION	NUCLEATE BOILING	FILM BOILING
TURBULENCE THROUGH HIGH LIQUID VELOCITY	TURBULENCE THROUGH BUBBLING & TWO PHASE FLOW	LAMINAR VAPOUR FILM BLANKETS SURFACE
LOW ΔT OR HIGH BACK PRESSURE HIGH FLOWRATE AND/OR MULTI PASS HEAT EXCHANGE	MODERATE ΔT 'WETTABLE' SURFACE MINIMAL BACK PRESSURE	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 $\Delta T < 40\ ^oC$
    - Low for Film Boiling – high ΔT
    - 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 – less frequent CIP

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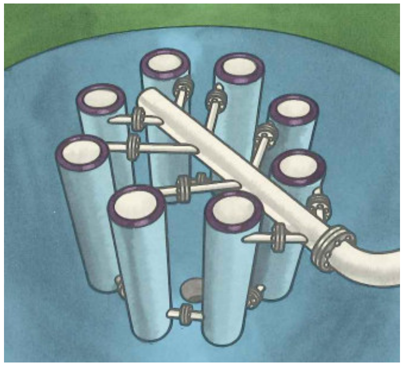
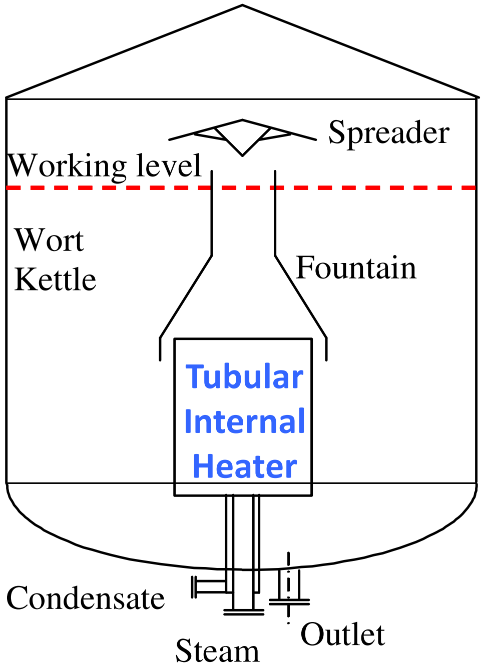
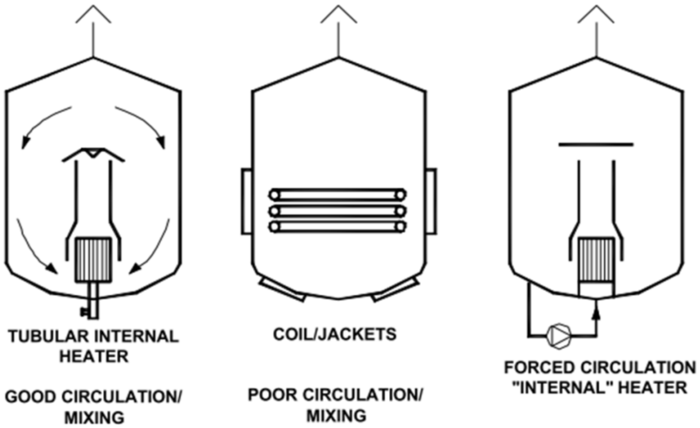
Wort Boiling - Internal Wort Heater

- Traditional
  - e.g. North America
- Percolators
  - Very low Surface area
- Tubular Internal Heater
  - Low Surface Area
    - Typically 0.08 m^2/hl
- Needs frequent CIP
- Fountain & Spreader
- May be pump assisted
  - Similar to External Heater



Percolator



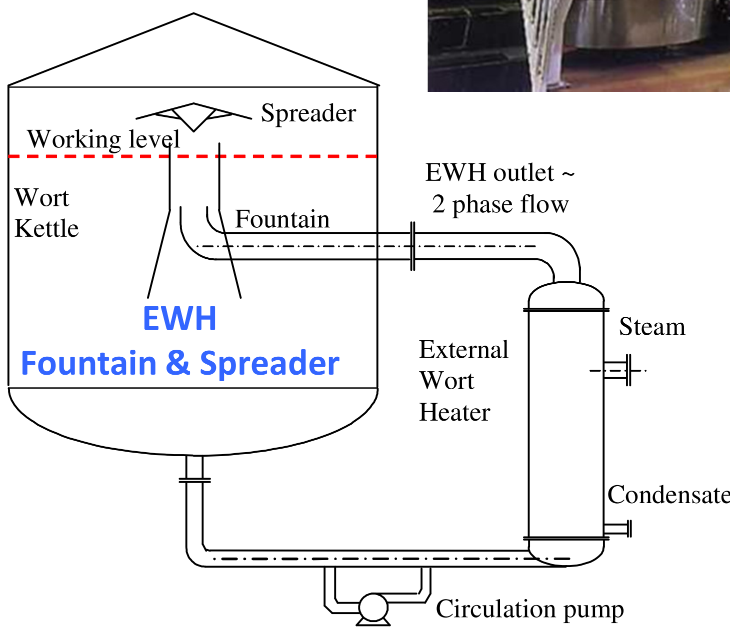


Wort Boiling – External Wort Heater

- 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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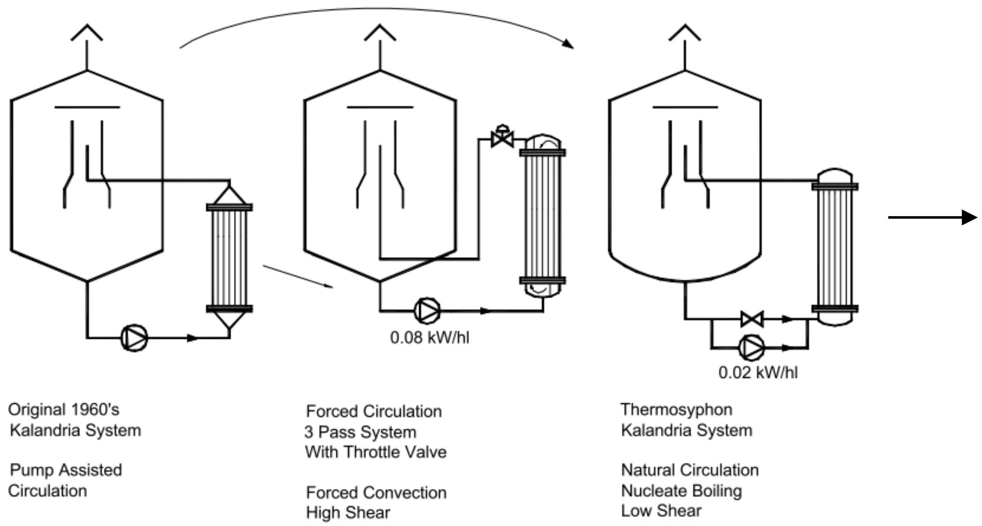
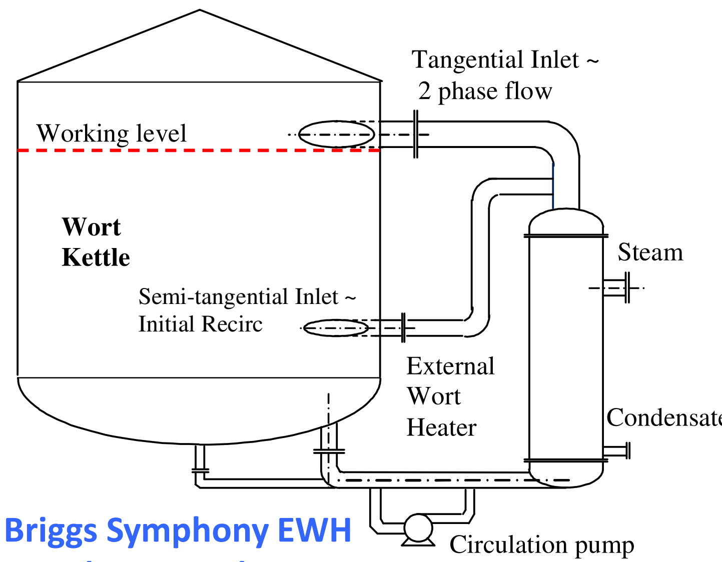
External Wort Heating Development





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.
High Elec power.

Back pressure, restricted outlet

Natural Circulation
Thermosyphon
Long tube

Long Tubular heater.

Higher surface area.

Large outlet.

Natural circulation during boil.

No boil pump power use

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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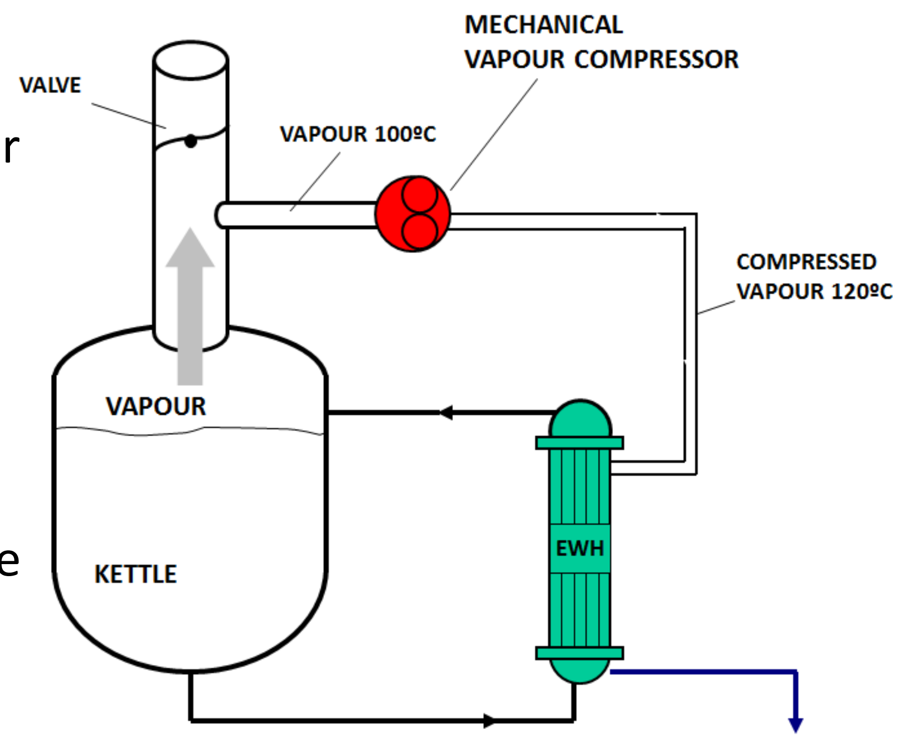
MVR – Mechanical Vapour Compression

- 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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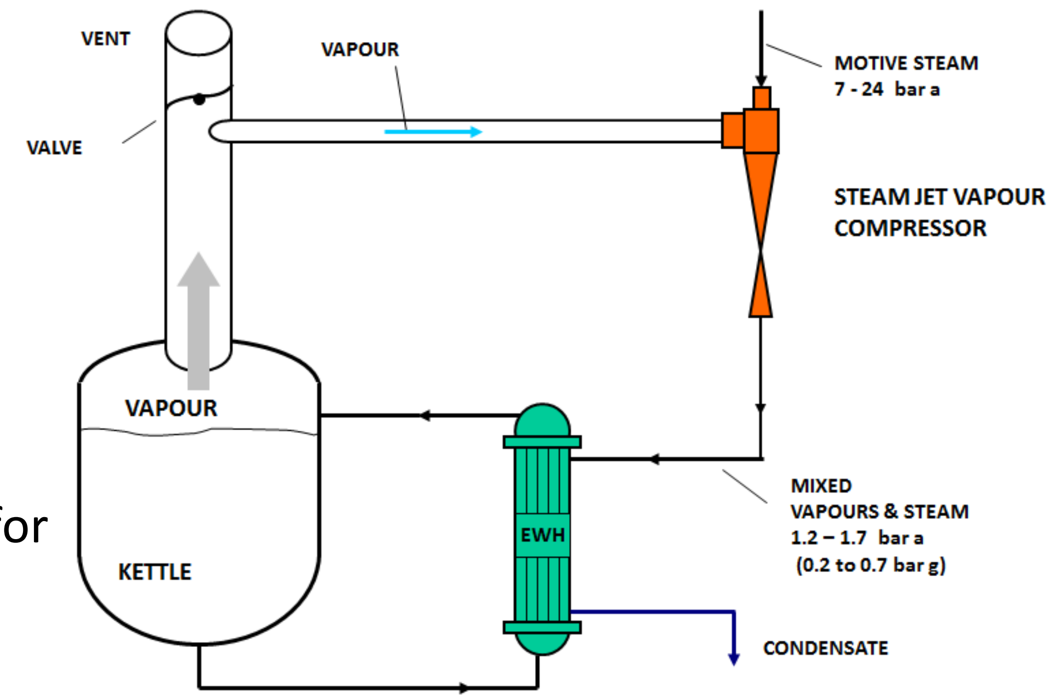
TVR – Thermal Vapour Compression

- 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



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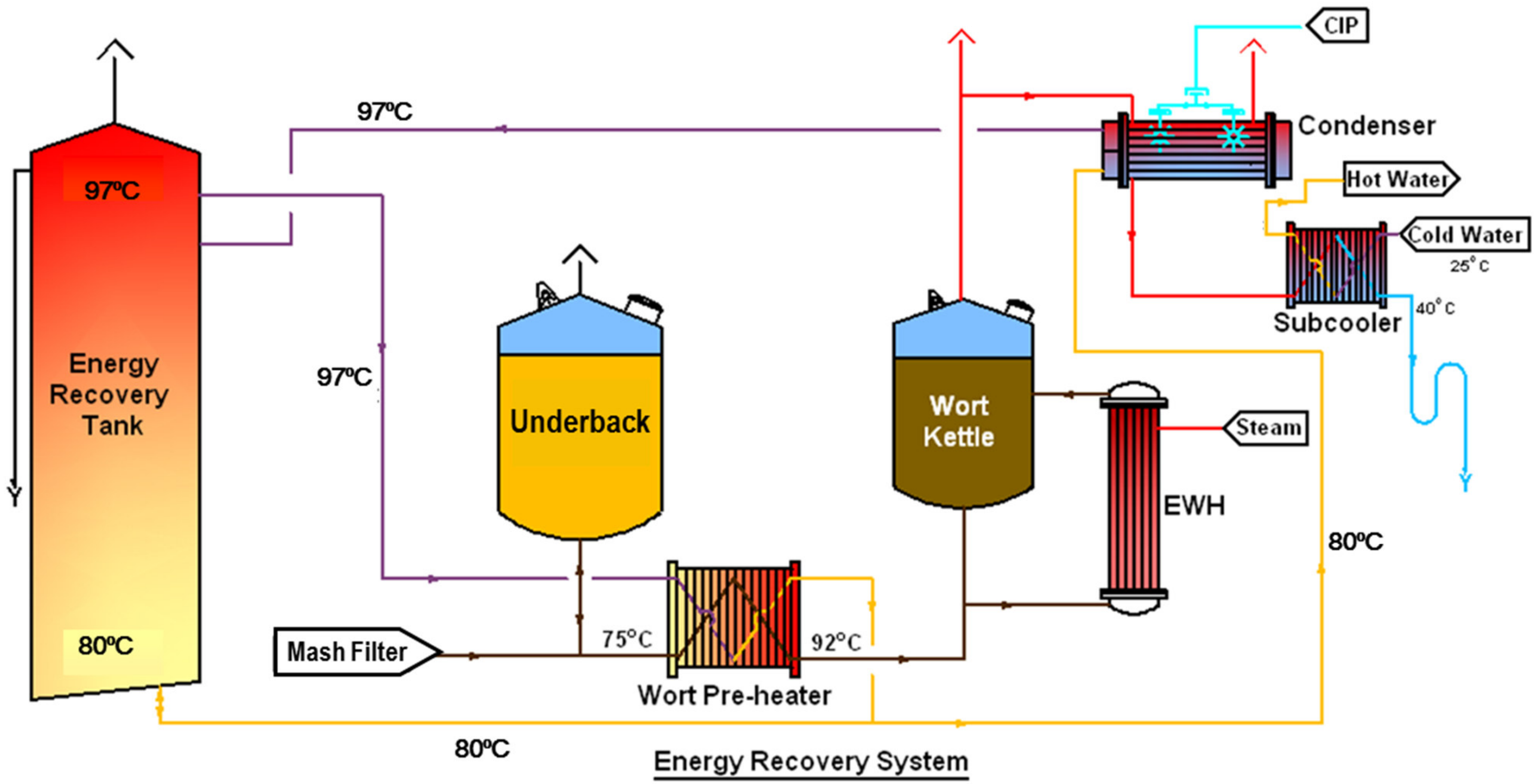
Energy Store – Wort Pre-heating



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Energy Recovery - Wort Pre-Heating

- Heating Energy = M x C_P x (T_2 – T_1)
- <u>No Energy Recovery</u>
  - Heat 1000 hl wort (1060 SG) 75 to 100 °C

    = 103,200 x 4.0 x (100 – 75) = 10,320,000 kJ

    = 10,320 MJ
- <u>With Wort Pre-heating</u> to 92 °C
  - Heat 1000 hl wort – 92 to 100 °C

    = 103,200 x 4.0 x (100 – 92) = 3,302,400 kJ

    = 3,302 MJ
- Energy Saving = 10,320 MJ - 3,302 MJ = 7,018 MJ

  = 68% reduction

  Steam Saving = 7,017,600 kJ / 2,133 kJ/kg = 3,290 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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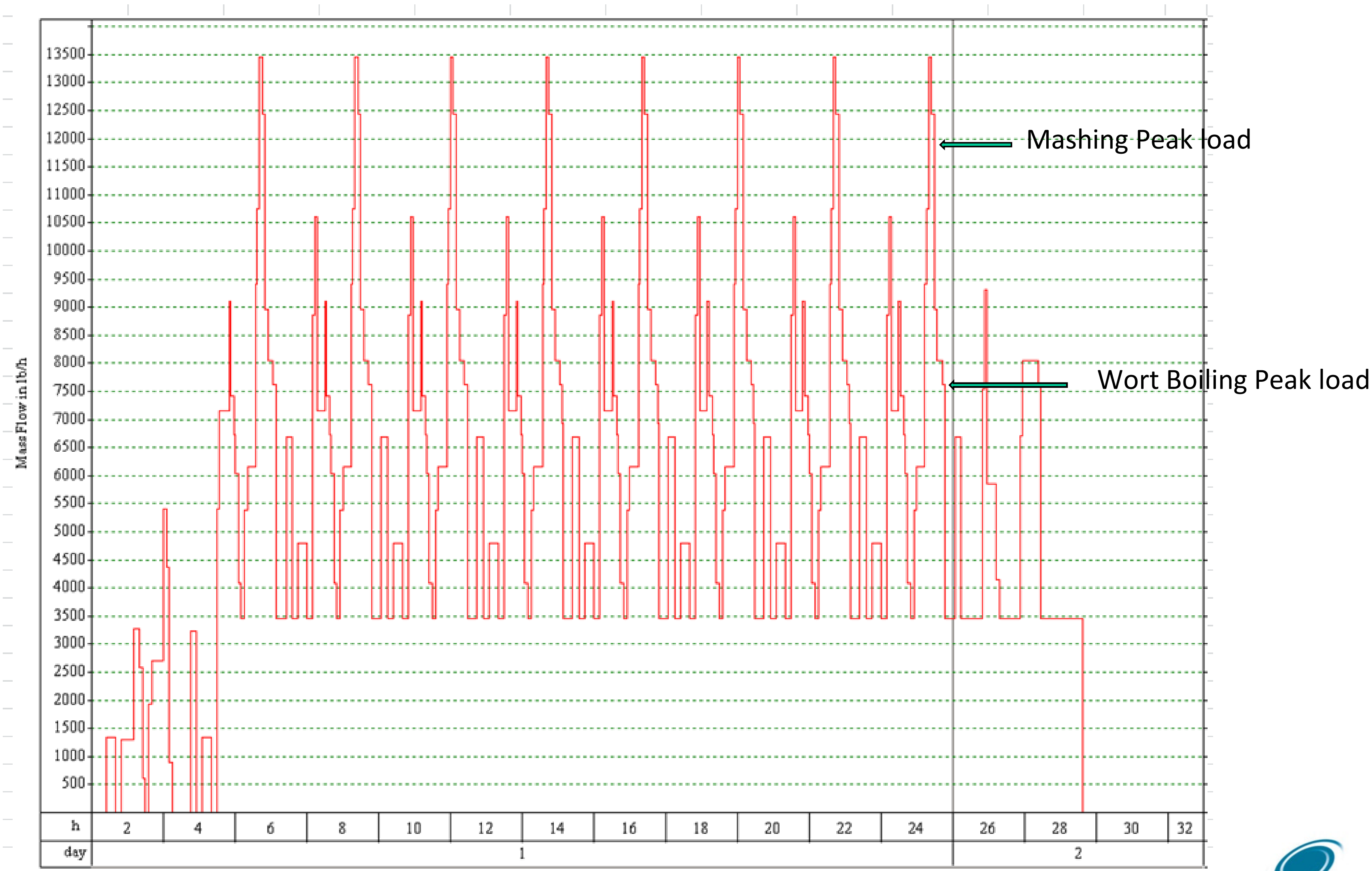
Heat Energy Provision & Balancing



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Short TAT Brewhouse

- More brews/day x Smaller Brewlength
- More frequent peaks
- Lower peak load
- Overall 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

Continuous Brewhouse

- Comparison -
  - Batch –
    - 200 hl x 14 BPD
    - 350 hl x 8 BPD
  - Continuous – 115 hl/h
- Small plant size – 60% vs 14 BPD
- Reduced losses & energy consumption
- Smooth utility load – minimal peaks
- Minimal starts / stops

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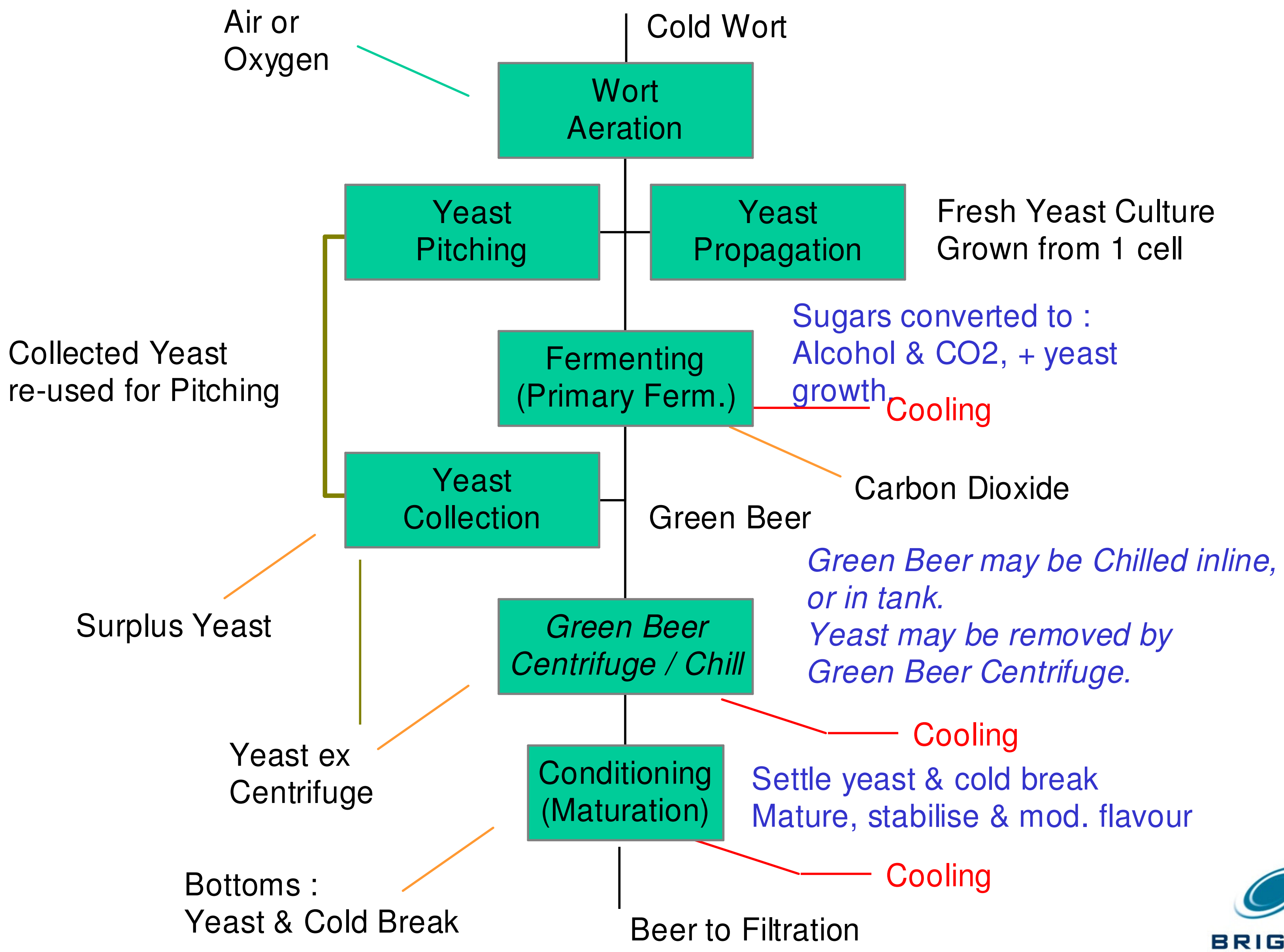
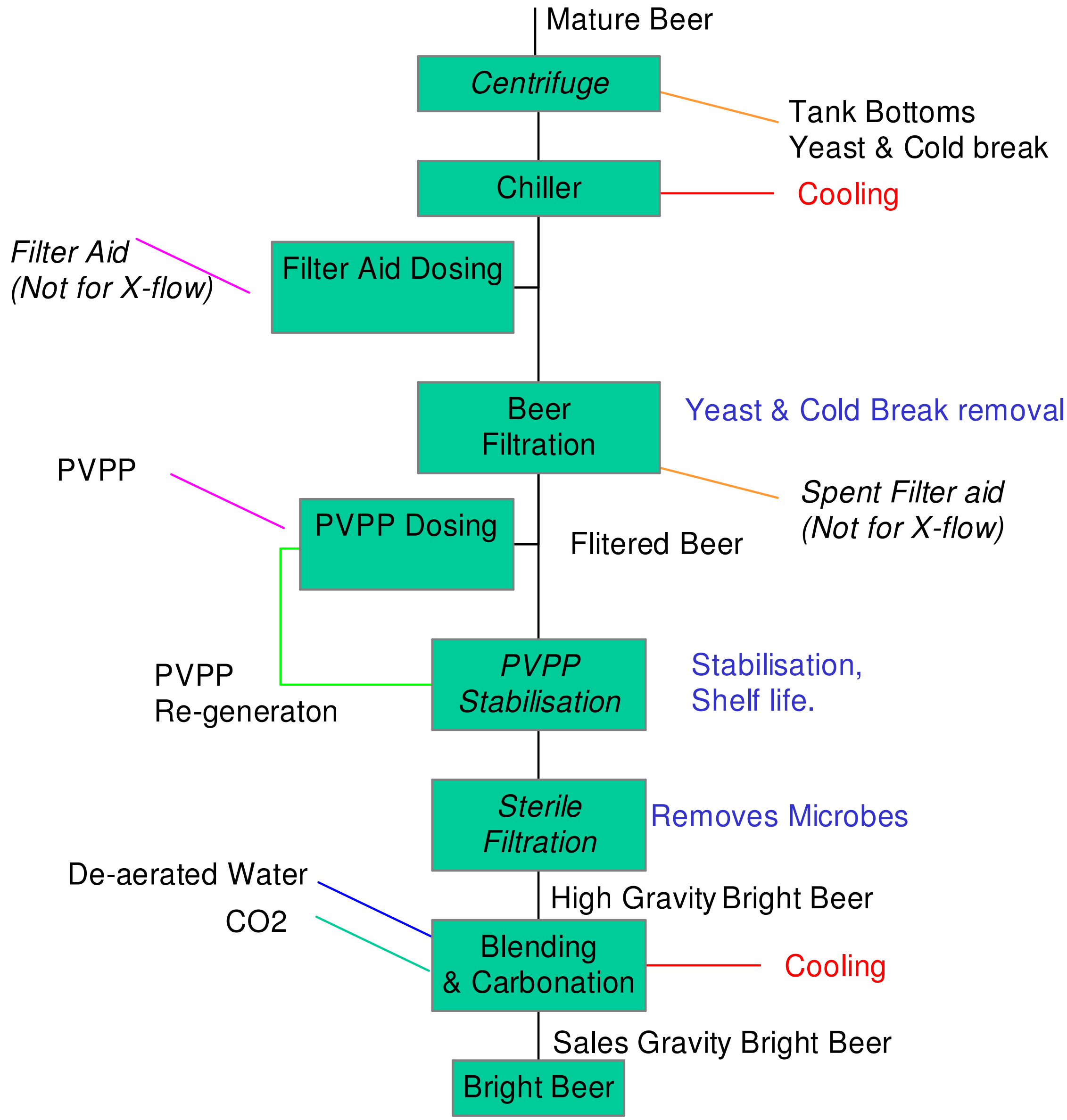
Fermenting & Conditioning - Process Flow



Filtration & Process – Process Flow



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Cold Process - Refrigeration duties

- Key locations requiring refrigeration & reasons to chill:
  - Yeast = Maintaining yeast viability & vitality
    - Propagation system – Vessel cooling
    - Collection system – Vessel cooling
  - Fermentation/Storage = Control of fermentation profile
    - Temperature control of fermentation profile – Vessel/HEX
    - Rapid chill back – Vessel/HEX
    - Maturation - Vessel
  - Filtration & Blending = Improved filtration (preventing chill haze) & improving CO_2 solubility
    - Chilled de-aerated blending water – HEX
    - Pre-filter – HEX
  - Bright beer Tanks = maintenance of product quality and packaging efficiency
    - Storage – Vessel Cooling

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Typical Cold Process Operating Temperatures

Operation	Ale	Lager	Stout
Ferment	18-22°C	10-12°C	20-24°C
Yeast Crop	10-12°C	4-6°C	N/A
Green Beer	10-12°C	1-3°C	3-4°C
Condition	N/A	-1.5°C +/- 1°C	0°C

- Wide range of operating temperatures
- Conventionally, same coolant temperature used for all
- Potential for increased efficiency through multiple coolant supply temperatures
- However adds complexity

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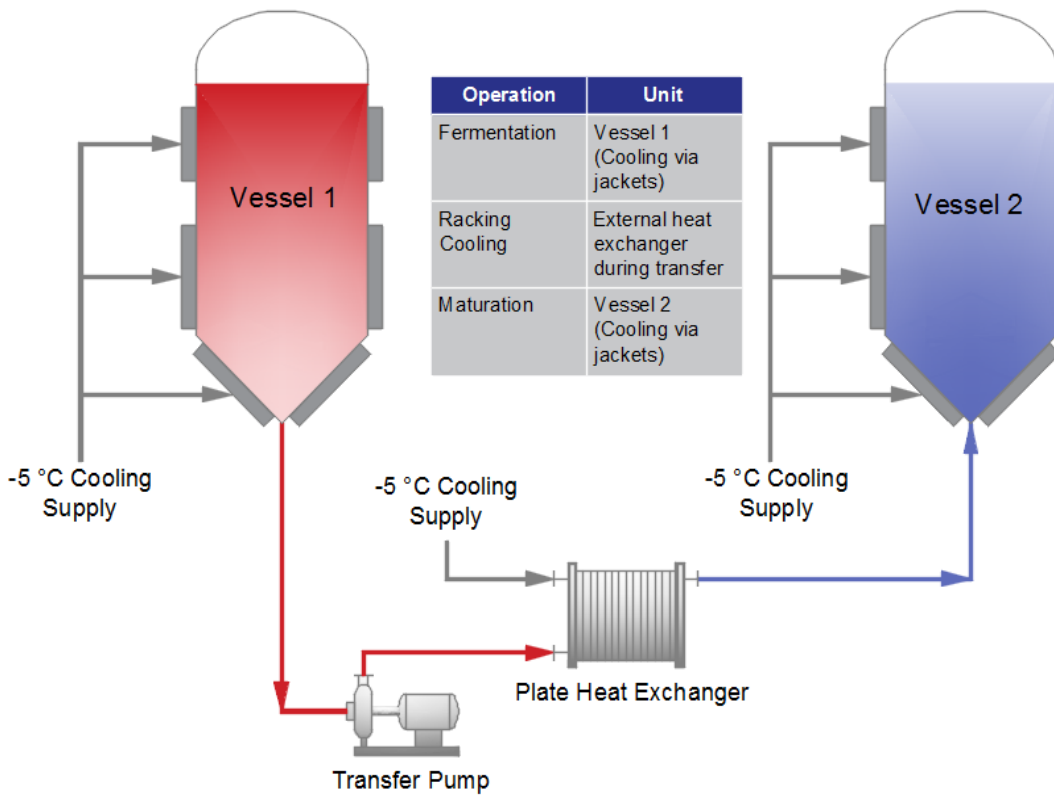
Fermenting and Maturation – Separate Tanks

Separate fermentation and maturation vessels

- DPVs or dedicated FVs & CTs
- Jacket cooling
- Low temperature chill in-line

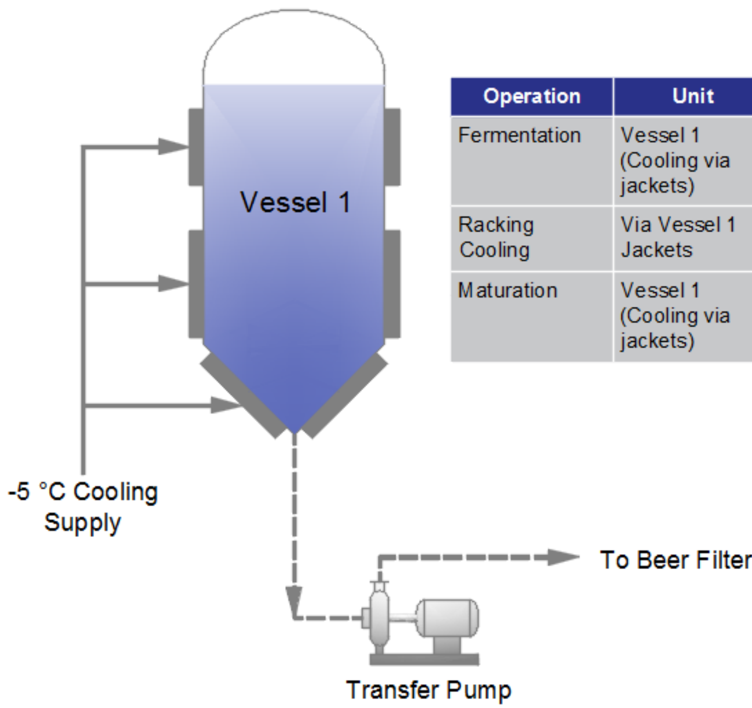


Operation	Unit
Fermentation	Vessel 1 (Cooling via jackets)
Racking Cooling	External heat exchanger during transfer
Maturation	Vessel 2 (Cooling via jackets)

Fermenting and Maturation – Unitanks

Single vessel only

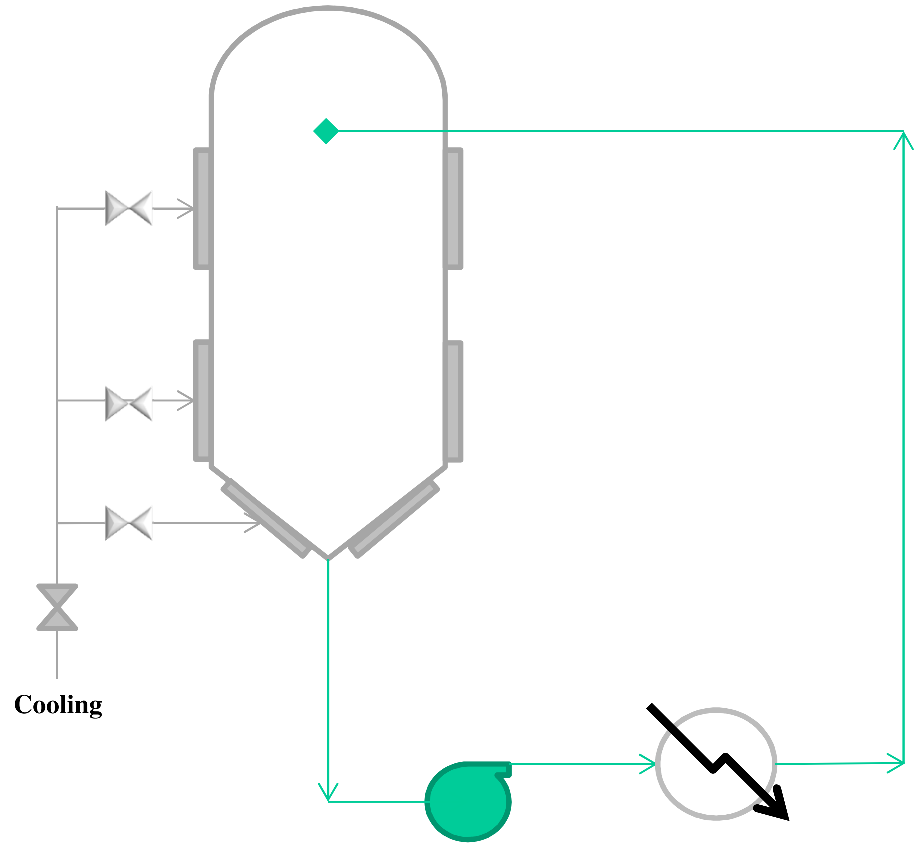
- Fermenting, Chilling & Maturation
- Chill in tank – Jackets
- Transfer to Filter only



Operation	Unit
Fermentation	Vessel 1 (Cooling via jackets)
Racking Cooling	Via Vessel 1 Jackets
Maturation	Vessel 1 (Cooling via jackets)

Fermenting – External Chilling & Dynamic Mixing

- Advantages
  - Removes limitation of jacket surface area, especially important on large vessels
  - Increased surface area and so decreased chill back time
  - Enables vessel agitation so decreased fermentation time
  - Reduced jacket area which can save costs



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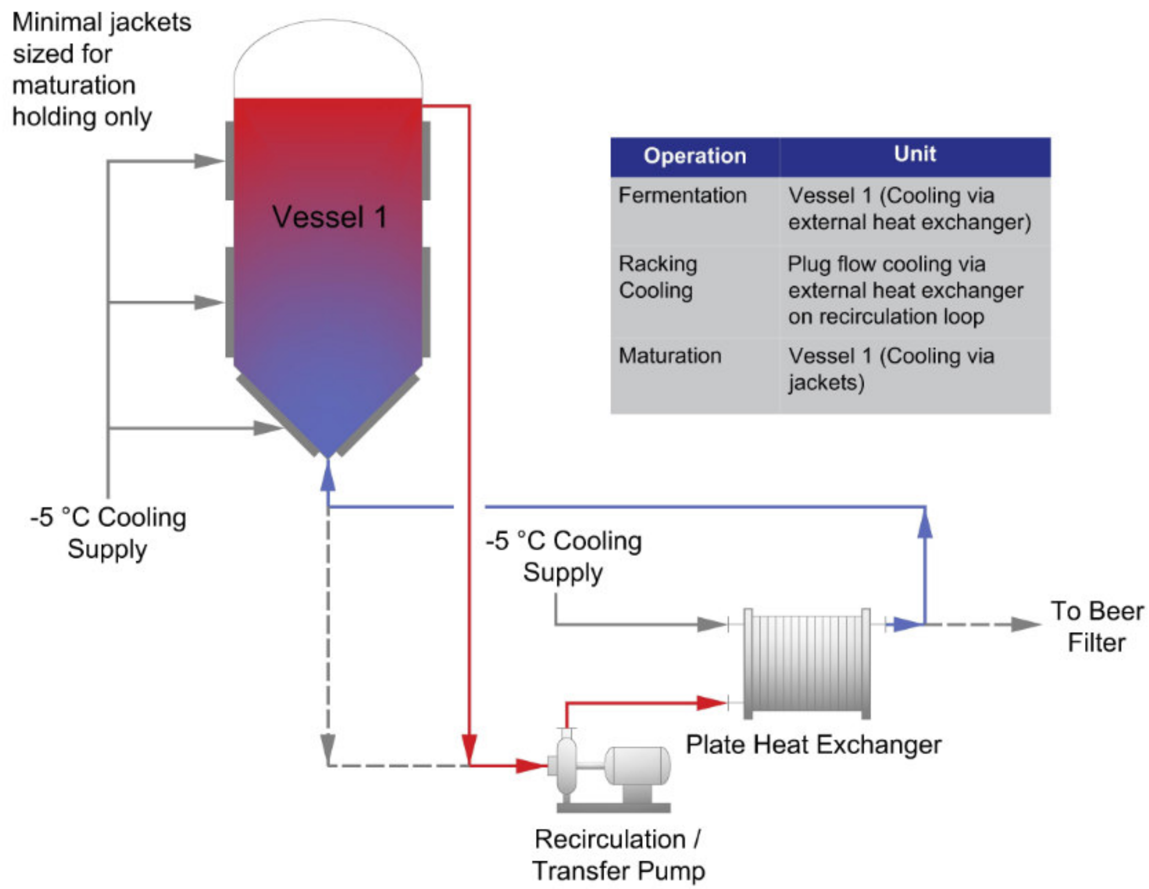
Fermenting - External Plug Flow Chilling

Single vessel only

- Fermenting, Chilling & Maturation
- External Chilling – top to bottom plug flow
- Single stage
  Coolant
  1. - 5^{o}C



Operation	Unit
Fermentation	Vessel 1 (Cooling via external heat exchanger)
Racking Cooling	Plug flow cooling via external heat exchanger on recirculation loop
Maturation	Vessel 1 (Cooling via jackets)

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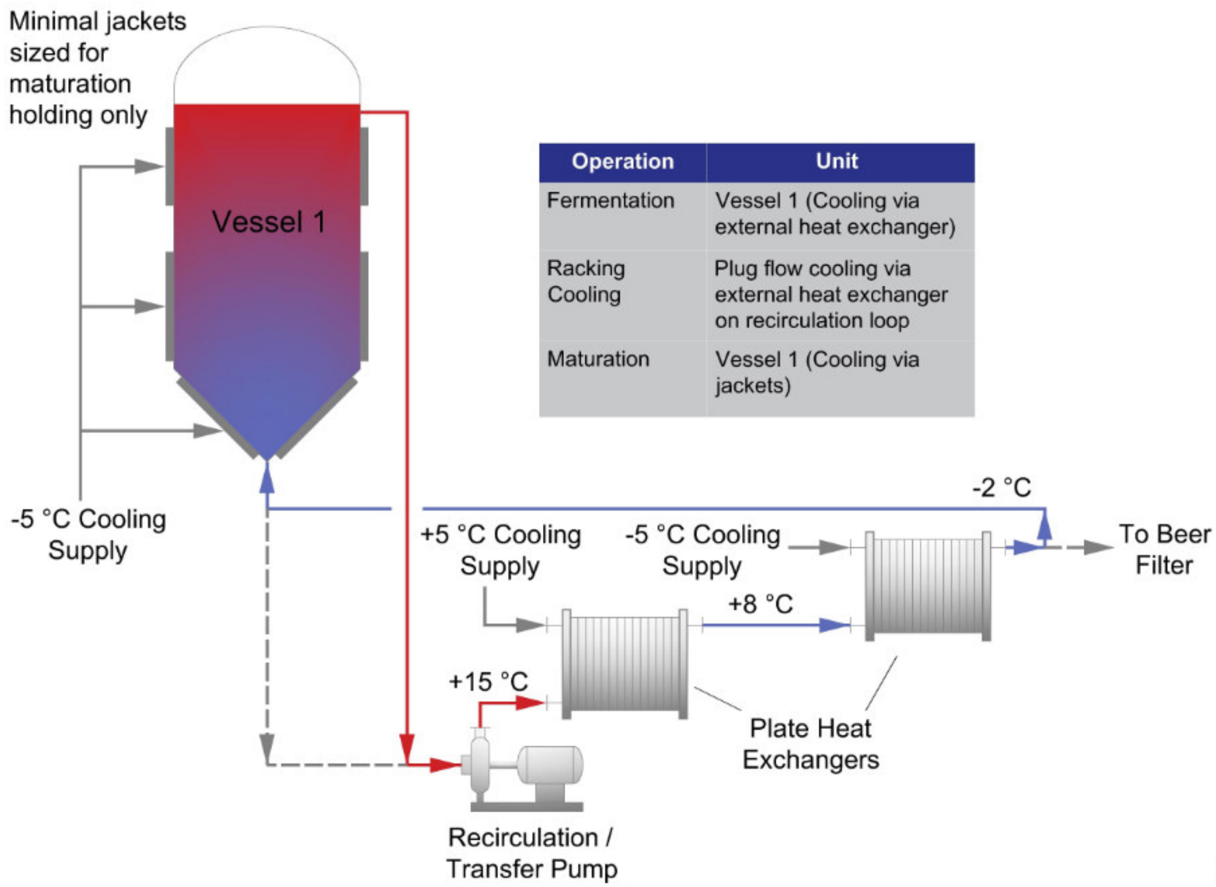
Fermenting - External Plug Flow Chilling

Single vessel only

- Fermenting, Chilling & Maturation
- External Chilling – top to bottom plug flow
- 2 Stage Coolant
  1. + 5°C
  2. - 5°C



Operation	Unit
Fermentation	Vessel 1 (Cooling via external heat exchanger)
Racking Cooling	Plug flow cooling via external heat exchanger on recirculation loop
Maturation	Vessel 1 (Cooling via jackets)

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Beer Filtration - Technology

- Filtration options
  - DE vs membrane
  - Types of membrane system
    - Pre-Filter Centrifuge?
    - Batch
    - Continuous
- Stabilisation options
  - Single use / total loss - Silica gel or PVPP
  - Conventional Regen PVPP
  - Modular / continuous PVPP

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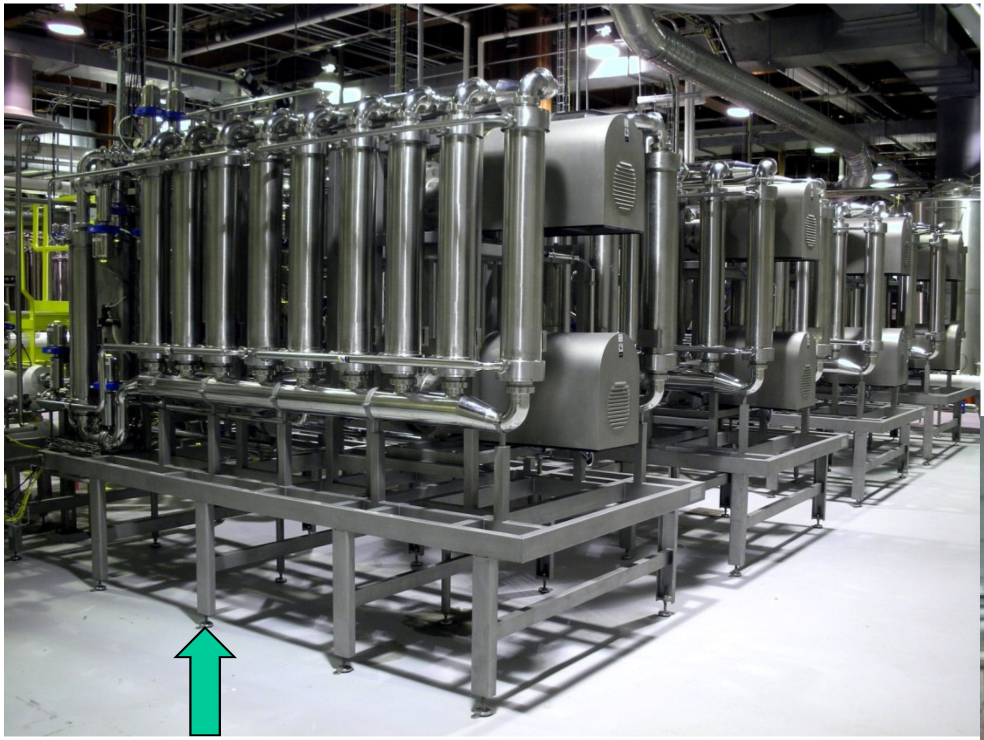
Membrane Filtration



- 470 hl/h Membrane Filter Stream
- One of 2 streams installed in 2007
- Pall Membrane technology
- Continuous system

- 400 hl/h Membrane Filter Stream
- One of 2 streams installed in 2015
- Pentair Membrane technology
- Batch system

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Membrane Filtration vs DE

Filter Media	• Lower cost than DE	10 – 30%
Electrical Energy Cost	• Comparable to DE • 0.3 –0.6 kWh	
Thermal Energy Cost	• Lower than DE	60 – 75%
Water Consumption	• Lower than DE • Water consumption < 0.15 hl/hl beer	25-40%
Manpower	• Lower than DE	80%
Disposal Cost	• Lower than DE	>95%
Service Cost	• Lower than DE	30 –50%

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DAW Systems - Technology

- DAW generation technology
  - N_2 vs CO_2
  - Hot or cold
  - Gas stripping vs cross flow
- Choosing a DAW storage temperature
  - Blending largest user
  - Hold at max temperature possible to achieve blended beer temperature to reduce energy loss
- Do you need to DAW flush?
  - If DAW not required used chilled water (e.g. yeast flushes)

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DAW Generation

- Cross flow DAW plant
- 950 hl/h capacity
- Centec Technology
- Installed 2015, UK

- CO2 Stripping DAW plant
- 300 hl/h capacity
- Alfa Laval, Aldox Technology
- Installed 2012 Uganda

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Process Cooling
Direct Expansion Refrigerant

- Indirect –
  - Glycol -5°C in
  - NH_3 -10°C
- Direct –
  - NH_3 -3°C in & out
- 20% reduction in refrigeration electrical power

Heat Exchange - Close Approach

- Q = U x A x ΔT
- Close approach = minimise ΔT
  - Higher Coolant Temp
  - Less refrigeration energy
  - Lower operational cost
- Higher UA needed
  - Greater surface area A
  - Greater capital cost

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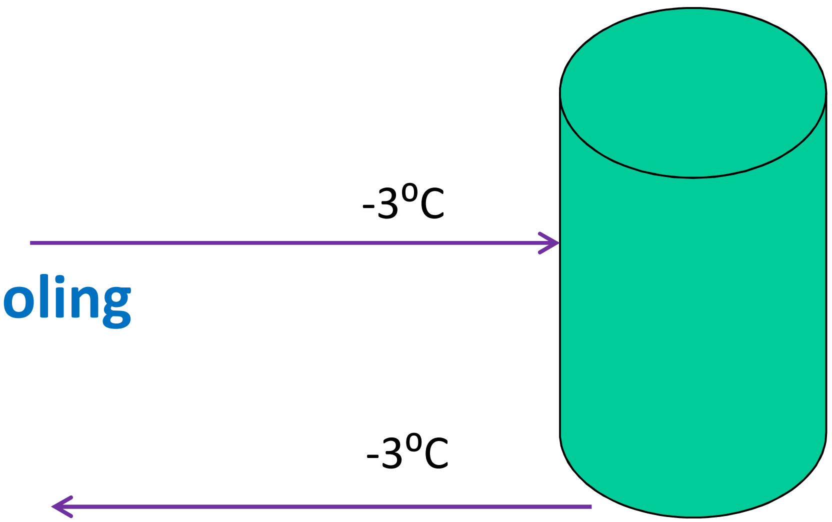
Refrigeration concept vs Process Duty

Primary



Direct expansion cooling on to vessel e.g. Ammonia

<u>Each additional circuit = loss in efficiency</u>

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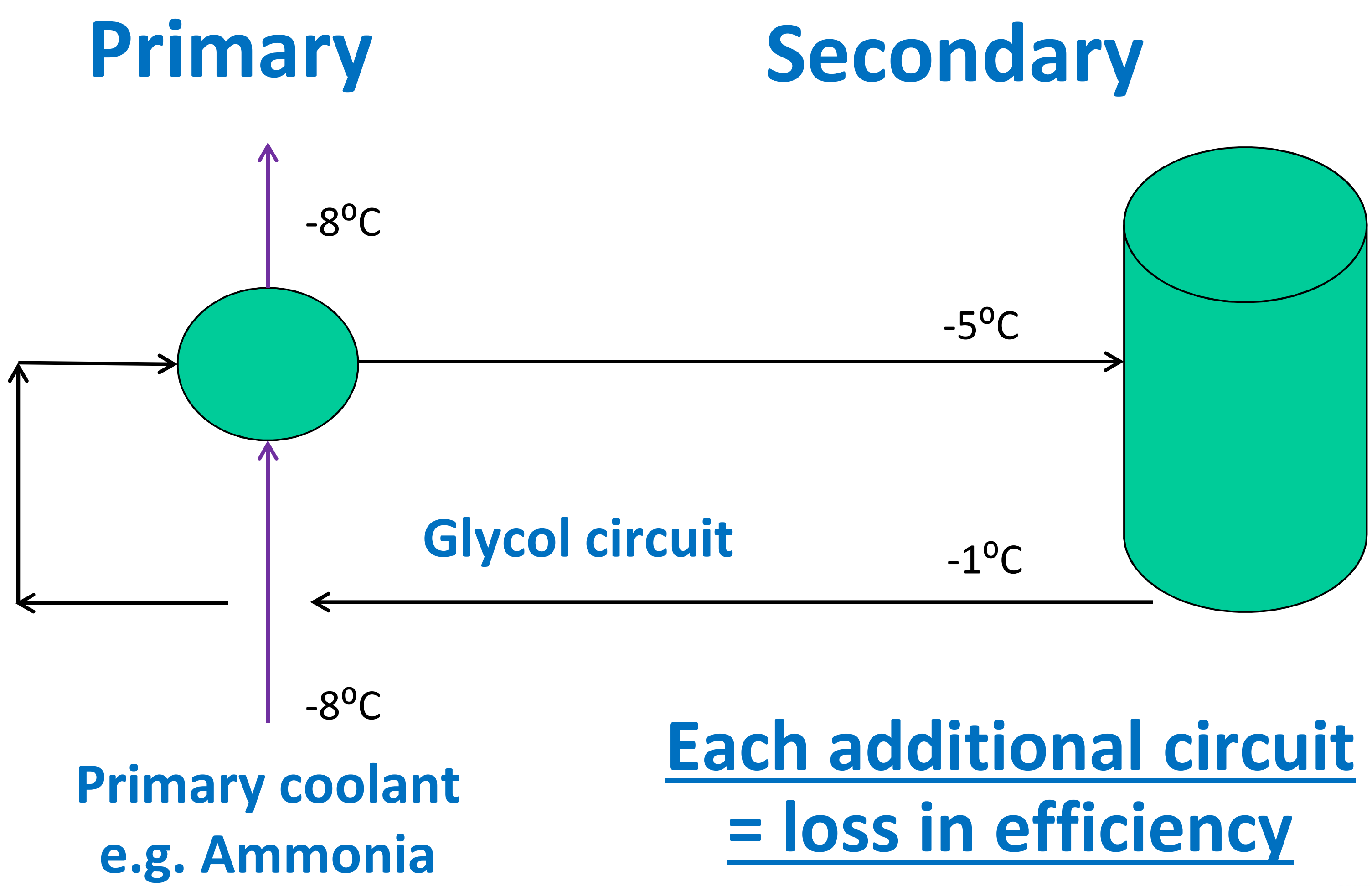
Refrigeration concept vs Process Duty



Each additional circuit = loss in efficiency

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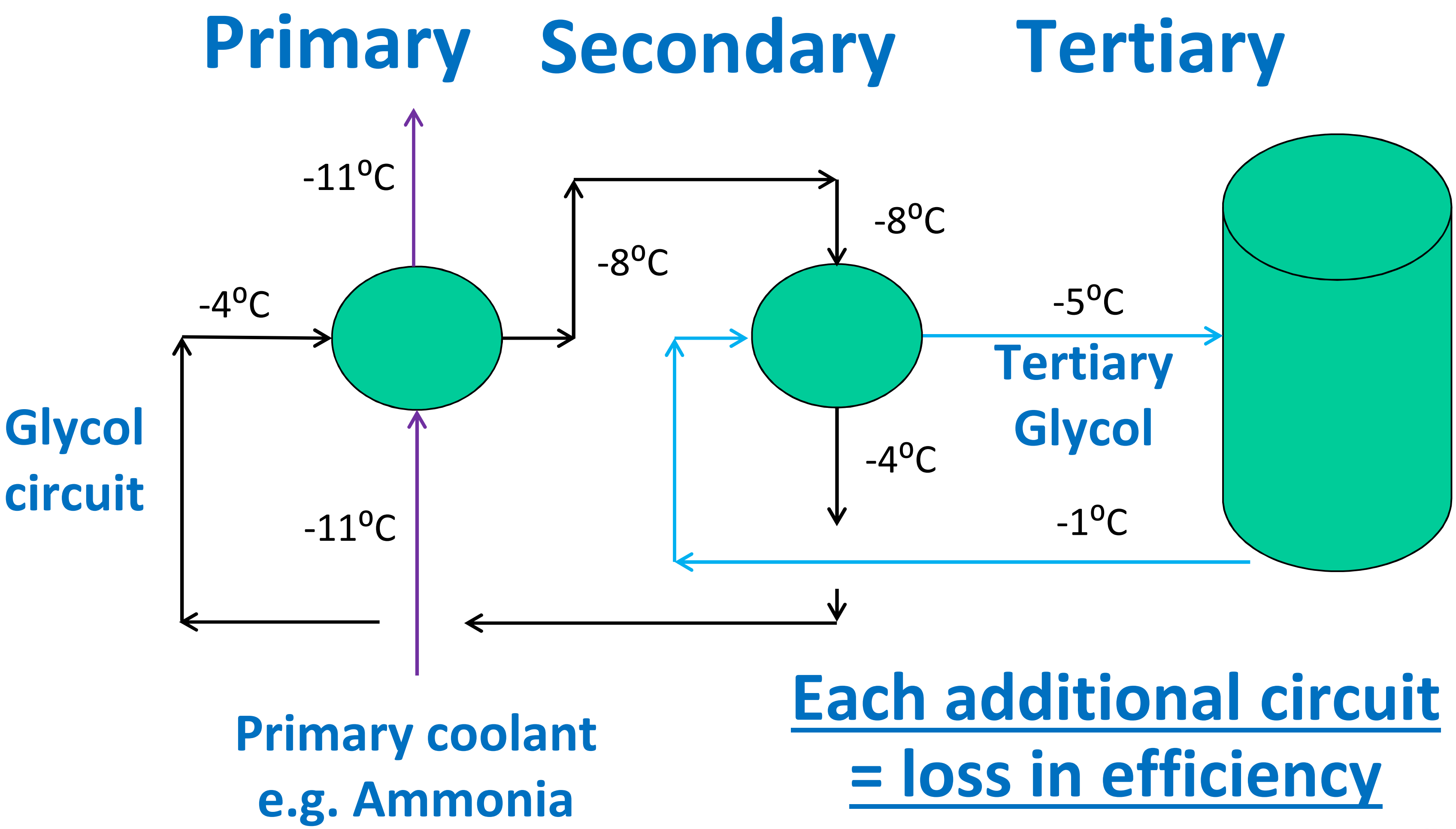
Refrigeration concept vs Process Duty



<u>Each additional circuit</u>

<u>= loss in efficiency</u>

COP & Refrigerant temperature

- COP = Q/P

Where:

Q = Refrigeration energy (kWr)

P = Power Input (kW)

<u>The Higher The Better</u>

Can be estimated typically:

$$C_f = \frac{T_e}{T_e - T_c}$$

Where:

$$C_f = Carnot\ Factor$$
$$T_e = \text{Evap Temp (K)}$$
$$T_c = Cond\ Temp\ (K)$$

COP = (0.5-0.7) C_f

Primary Fridge Circuit	Evap Temp °C	COP (Est)
1	10	6.2
2	5	5.0
3	0	4.1
4	-5	3.5

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Pipe Sizing

- Under sizing of process pipework can be attractive due to lower installed capital cost , but has long term energy implications

Dia mm	50	75	100	125	150
Capital Cost £ (Material & Installation)	£ 2,796	£ 3,854	£ 5,485	£ 7,533	£ 9,252
Relative Capital Cost	51%	70%	100%	137%	169%
Relative Velocity	400%	178%	100%	64%	44%
Relative Pressure Drop & Power Use	1600%	316%	100%	41%	20%

- Pressure drop is proportional to pipe velocity^2
    - ½ Diameter -> 2 x Velocity -> 4 x Pressure Drop
- Pump duty is a function of pipework pressure drop (+ Static head)
    - Power proportional to flow x pressure
    - 4 x Pressure Drop = 4 x Power use (+ Static head power element)
- Undersized pipework will mean long term high pump power use

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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 = $\dfrac{\text{Power Imparted on Fluid}}{\text{Power Supplied to Drive}}$
- 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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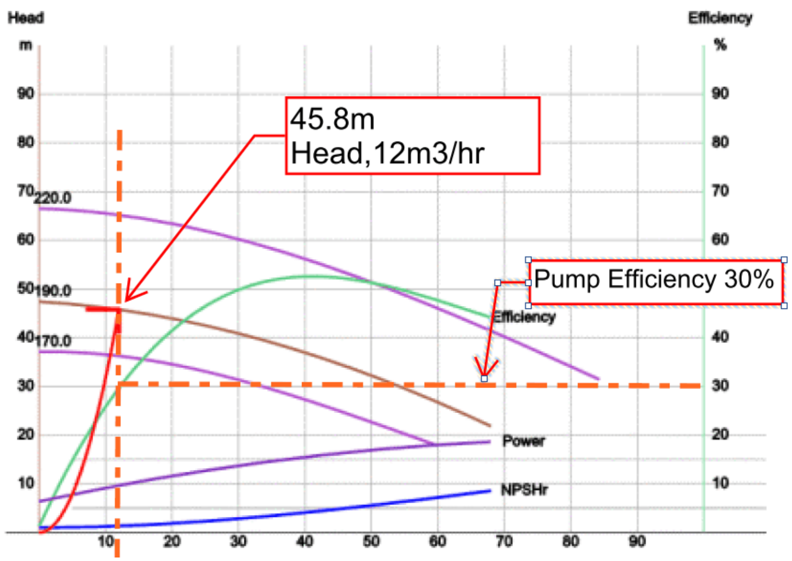
Pump - Capital Cost vs Efficiency

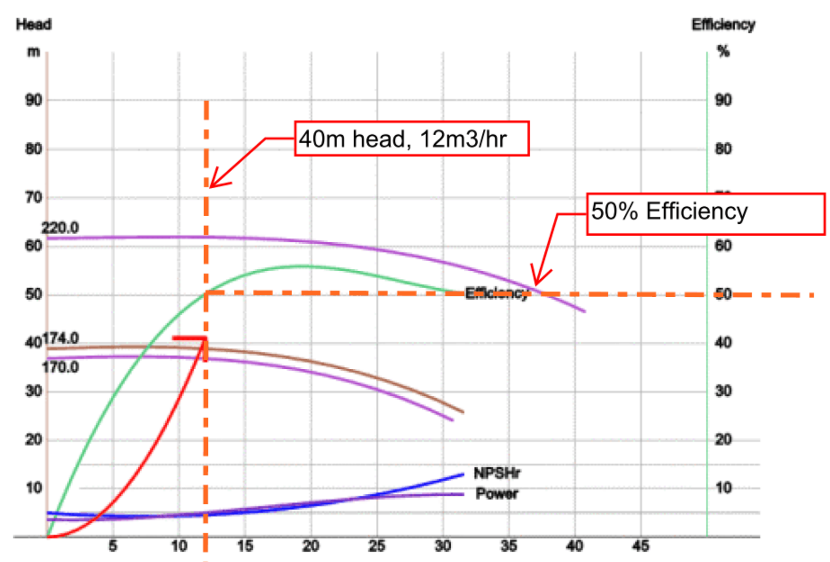


Low Capital Cost & Efficiency

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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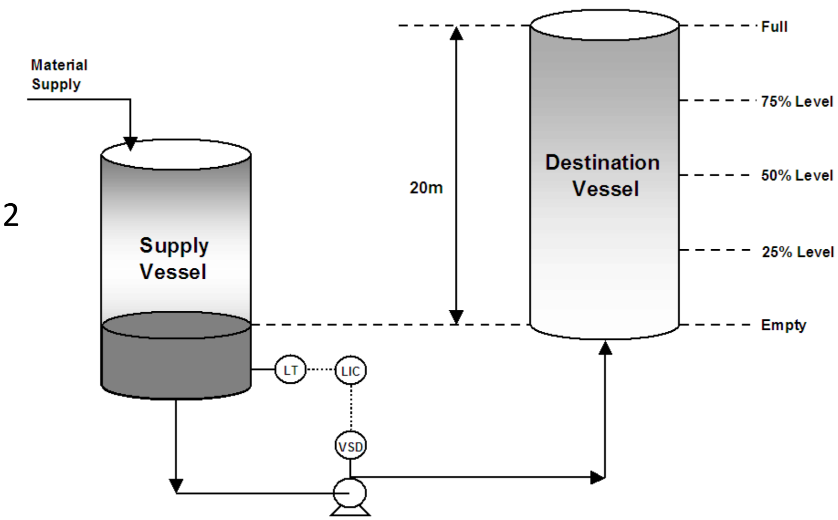
VSD Pump Operation

- 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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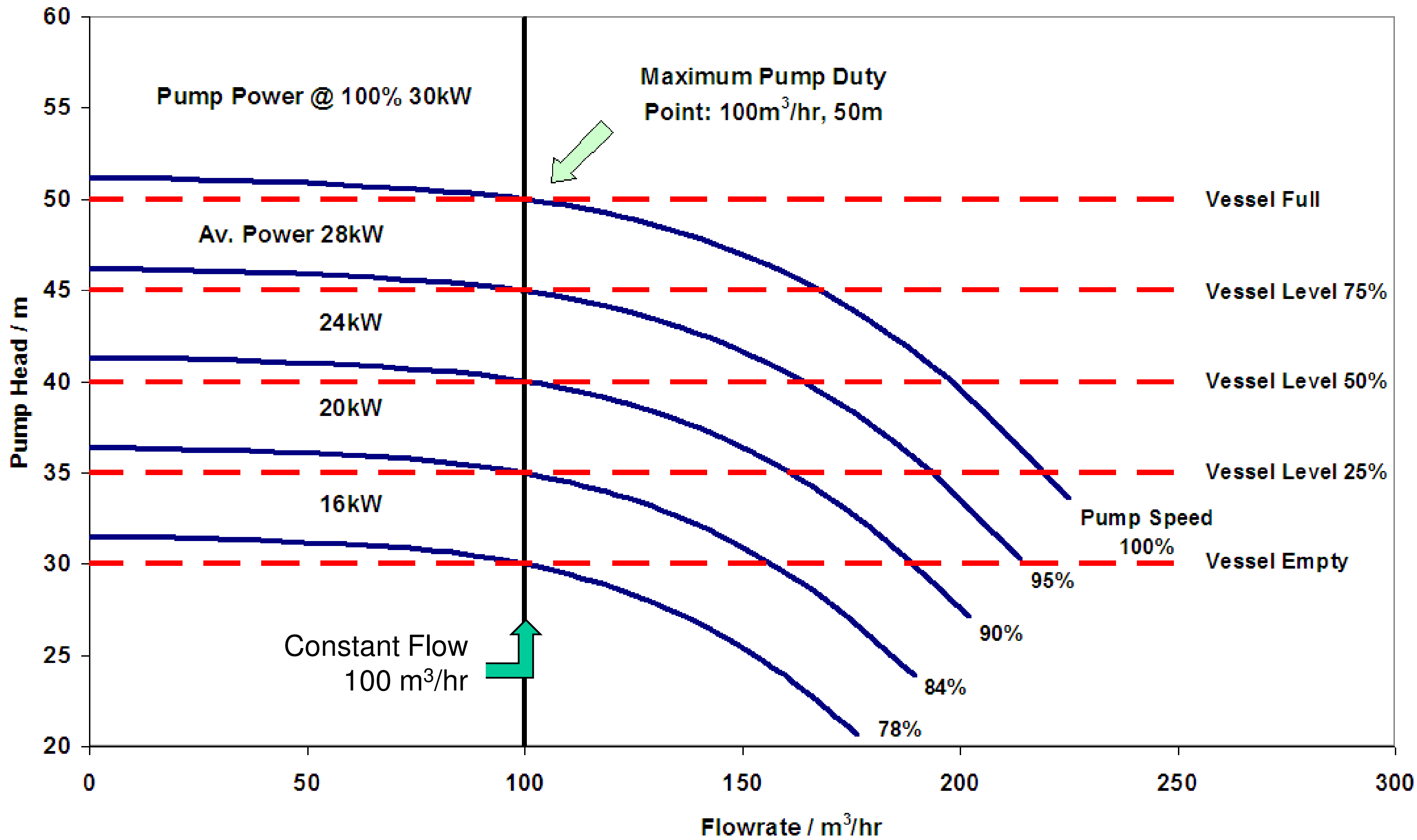
VSD Pump Curve



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 526 kWh
- Energy Consumption Reduction 26%

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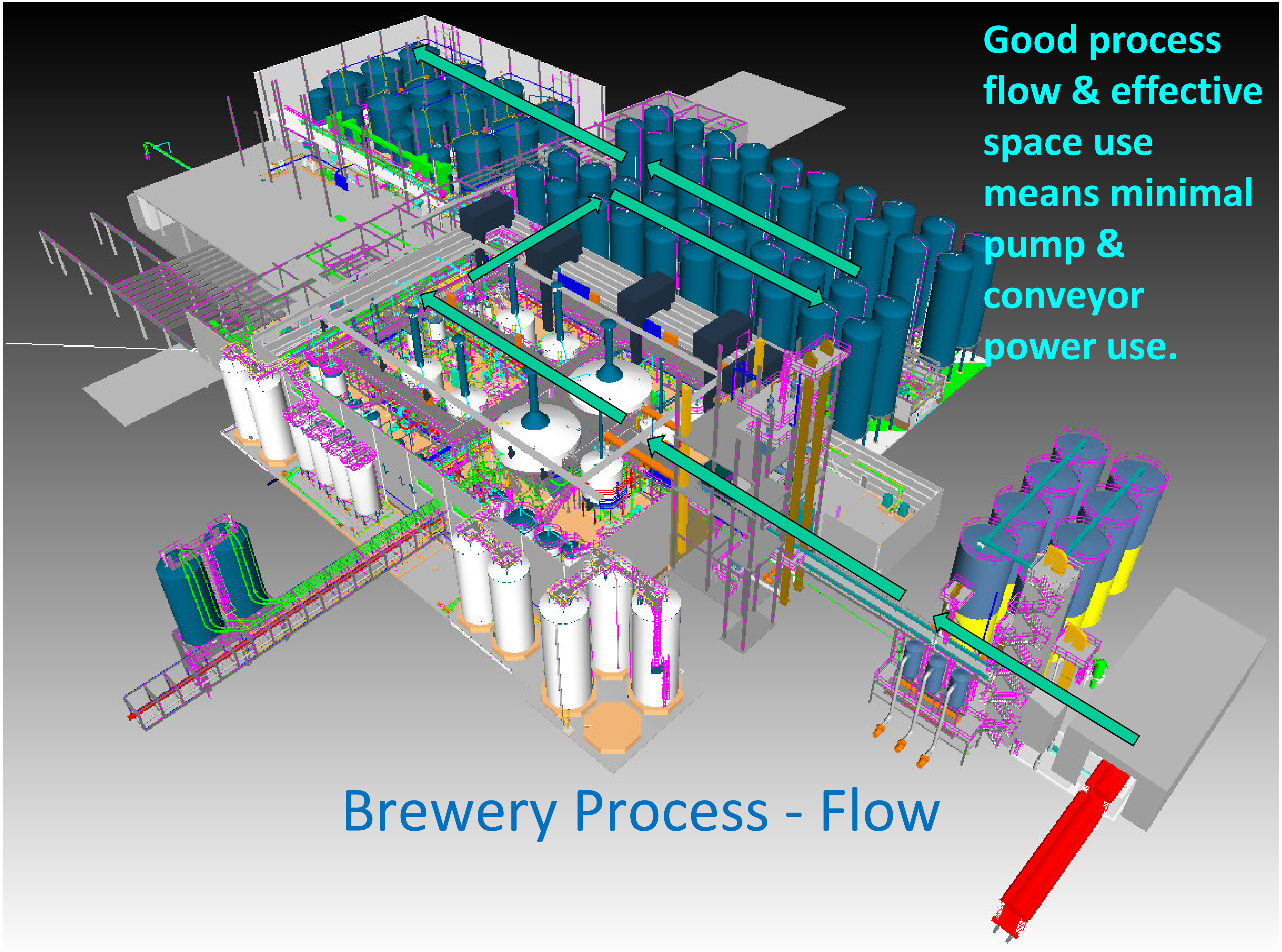

Brewery Process - Flow