Beer Brewing Unit Summary

- History of brewing
  - Brewing can be traced back to early civilization – beer at that time resembled porridge flavored by spices and essential oils
  - Roman empire brought beer to Northern Europe – Germany developed lager and UK more ales
  - Reinheitsgebot (1516) German standard for brewing (water, malted barley, malted wheat, hops)- defined beer for 500 years but revised in 2016 to allow greater variety of different beers
  - England was an industrial center for malt production and brewing but mainly ales at this time period
  - Innovations
    - 1762- Thermometer was introduced to brewing by M. Cumbrune;
    - 1769- Hydrometer introduced by J. Baverstock; 1843-
    - 1837 Balling – method to estimate alcohol production from wort
    - 1855-1875- Pasteur described fermentation in yeast
    - 1883- Emile Hansen introduced pure strain brewing
- Brewing industry has undergone consolidation – 75% owned by AB InBev-Miller. Large increase in craft brewer sector where diversification is key.

Advantages	**Disadvantages**
Scales of Economy	Narrow consumer choices
Efficiency	Exclude small breweries
Consistency	Control of raw material prices
Technology Advances	Price fixing
	Closures
	Less incentive to innovate

- Malt
  - Malt is germinated cereal grain (mainly barely) that is dried/roasted to varying degrees
  - Barley is preferred due to lower gelatinization temperature, high enzyme levels and moderate protein. 2 row barley preferred over 6 row barley due to even kernel size (aids milling) and low protein.
  - Malt provides
    - Enzymes (amylase, protease) required to hydrolyze starch to fermentable sugars and proteins for FAN
    - Impart flavor and color to beer
  - Malt classified based on diastatic power (amylase activity, °L (Lintner) and degree of roasting (Pale, Crystal, Chocolate, Black). Main purpose is to induce enzymes without degrading starch at this stage.

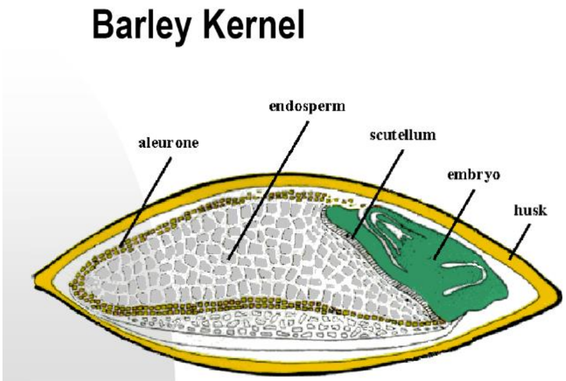

Figure 1: Diagram of a Barley kernel

- Kernel components:
  - Embryo- baby plant
  - Starch endosperm- food reserve for embryo and source of fermentable sugars in brewing
  - Aleurone layer- generates the enzymes that degrade the starchy endosperm
  - Husk- protective layer
- *Fusarium* head blight (FHB) and the presence of *deoxynivalenol* (DON) in barley impacts the the malt and the beer quality. DON should be less than 500 ppb
- Dimethyl Sulphite (DMS) adds a cooked corn flavour in beer
  - It is produced during grain germination
  - levels can be adjusted through kilning of malt (if high in pale malt) or boiling in the brew house (if volatile)
  - Ales can have 10-20 ppb DMS and lagers can have 40-175 ppb DMS
  - To control DMS levels: select 2-row pale malt, avoid corn adjuncts, boil wort for 90 mins or more in an open vessel, rapidly cool the wort, select yeast and ferment at a low temperature, and ensure beer aged sufficiently

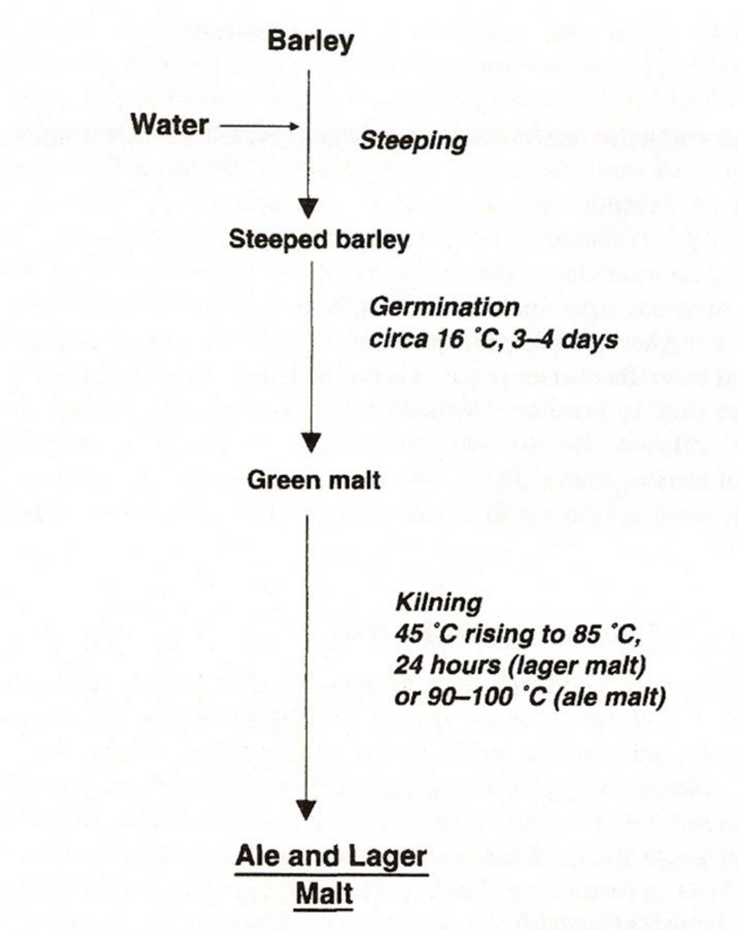

Figure 2: Malting Process

- Hops
  - *Humulus lupulus* grown around the world on 48th parallel
  - Flower contains *lupulin* with bitter substances (hops resins) and aromatic oils
  - Hops contain
    - Alpha acids which account for 90% of bitterness (Humulone, Cohumulone, and Adumulone). Requires to be isomerized by heating to release bitterness.
    - Beta acids (Lupulone, Colupulone, and Adlupulone)
    - Oils are responsible for the characteristic odour, they are volatile, major component is Humulene

Main form is pelleted form but also available as whole cones or extracts.

- Adjuncts provide extract at a lower cost than malt (can be corn, rice, barley)
  - Enhance physical stability, have superior chillproof properties and add brilliancy- low protein
  - Adjust wort fermentability
  - Corn and rice commonly used – requires to be gelatinized prior to use. Can also add sucrose or corn syrup

- Water is critical part of brewing process
- Requires to be potable and dechlorinated
- Aim to reduce water usage to 3-5 liters water per liter beer. Saves cost of water and wastewater treatment.
- Water typically striped of ions then reconstituted depending on beer being produced.

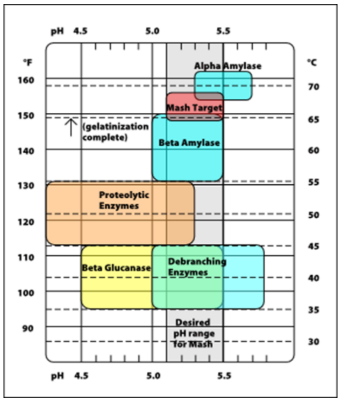

Figure 3: pH of mash needs to be between 5.1-5.6

Contributions to water pH
Bicarbonate – alkali water through sequestering protons
Calcium- combines with bicarbonate to form calcium carbonate – reduce alkalinity – increases acidity
Magnesium – competes with calcium – results in a lower reduction of alkalinity due to soluble salts
Malt- dark malt contains high level phytic acid complexed with phosphate. Phosphate released then combines with calcium (calcium phosphate) releasing protons – hence acidifying

Residual alkalinity – indicator of pH and buffering capacity of mash. High residual alkalinity – pH adjust by malt Low residual alkalinity – adjust by addition of calcium (gypsum)

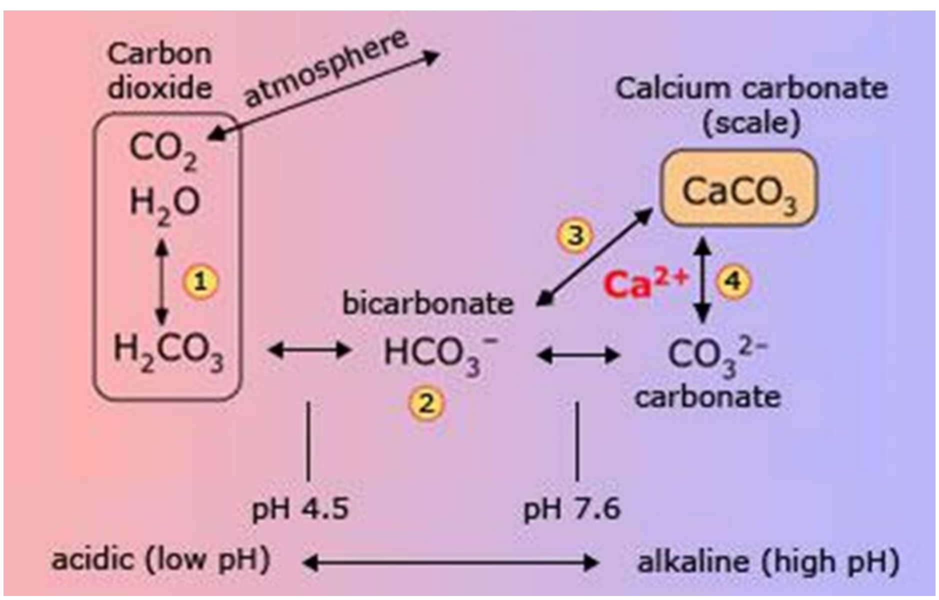

Figure 4: pH water chemistry

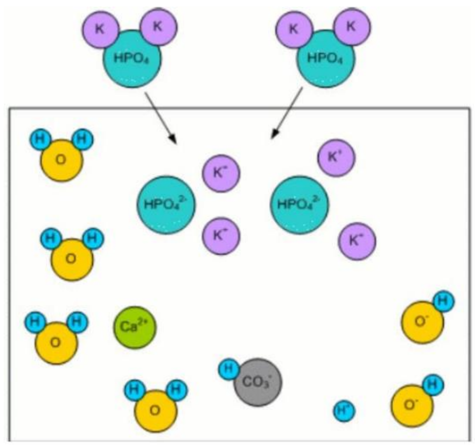

Figure 5: Effect of malt on pH

City	Calcium (Ca^{+2})	Magnesium (Mg^{+2})	Bicarbonate (HCO_3^{-1})	SO_4^{-2}	Na^{+1}	Cl^{-1}	Beer Style
Pilsen	10	3	3	4	3	4	Pilsener
Dortmund	225	40	220	120	60	60	Export Lager
Vienna	163	68	243	216	8	39	Vienna Lager
Munich	109	21	171	79	2	36	Oktoberfest
London	52	32	104	32	86	34	British Bitter
Edinburgh	100	18	160	105	20	45	Scottish Ale
Burton	352	24	320	820	44	16	India Pale Ale
Dublin	118	4	319	54	12	19	Dry Stout

Figure 6: Mineral content in common beer types

- Alkali pH: inefficient or inhibited mashing process, extracts tannins and phenolics from grains, extraction of harsh flavour notes from hops

Beer	Bicarbonate	Mineral levels	Malts	Additional comments
Pilsner	Low	Low	Pale	Hop flavour, bland beer, soft flavour
Vienna	High	Low calcium, high sodium	Dark, malty flavour	Dark lager
Burton-on-Trent	Balance hardness and alkalinity	High	Light roasted	Pale ale, minerals enhance hop flavour
Dublin	high	low	dark	Stout, hop bitterness

Table 2: Water quality for varying beer types

Sulphur –Dry flavor, enhances bitterness from hops
Chloride- enhances malty flavor
Dark malt- adds color, flavor, masks contribution for ions in the water.

- Yeast
  - Ideal yeast qualities include: rapid initiation of fermentation, high fermentation efficiency, high ethanol tolerance, desired flavour characteristics, high genetic stability, and range of alcohol production
  - Ale yeast: *S. cerevisiae*, top fermenter (yeast rises to top of fermenter), higher fermentation temperature.
  - Lager yeast: *S. pastorianus*, bottom fermenter (yeast sinks to bottom of fermenter), lower fermentation temperature
  - Top fermenter: forms thick layer on surface, requires 10-25 °C fermentation temperature, more fermentation by-products (higher alcohols, esters), differences may disappear with yeast recycling (limited pitching)
  - Bottom fermenter: lower fermentation temperature (5-15 °C), slower growing with less head formation, forms less by-products, used in 90% of world's beer production
  - Yeast condition:
    - Yeast viability- measure of alive yeast through microscopic techniques (physically test using methylene blue and eosin Y)
    - Yeast vitality- measure of how healthy the yeast is, sterol measurement, acidification power, oxygen consumption (physically test using acidification power and glycogen)
  - Yeast storage in sterile tanks, at temperatures of 0-4 °C, periodic gentle agitation keeps temperature uniform, alternative is yeast pressing into cakes

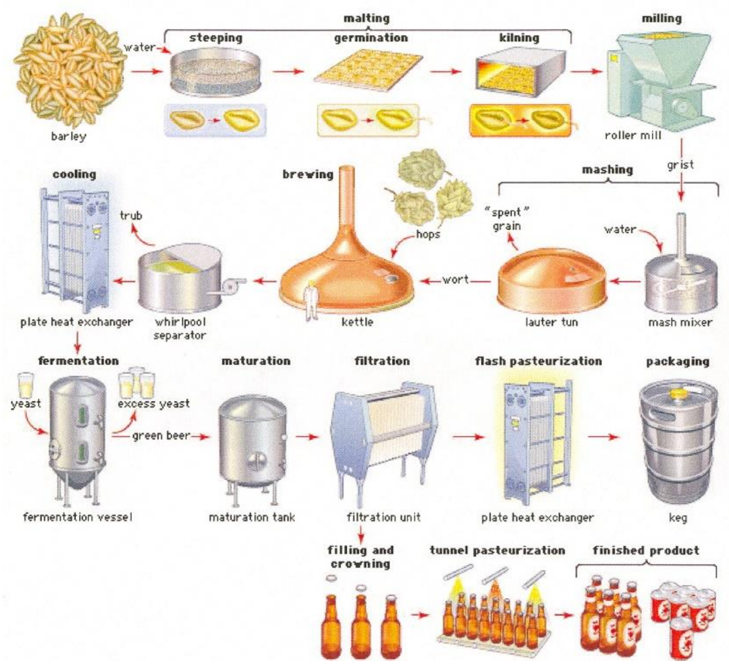

Figure 3: an overview of the brewing process

- Milling
  - The grain is processed through a roller mill (2, 4, or 6 roller), designed to leave the husk intact.
- Mashing
  - The crushed grain is mixed with water in a mash tun at proper volume and temperature;
  - Protein degradation- reduction of high molecular weight proteins to simpler amino acids (proteinase- reduce large proteins to medium sized proteins; peptidase- degrade medium sized proteins to amino acids for yeast growth)
  - Starch degradation- conversion of starch molecules to fermentable sugars (alpha amylase- rapidly reduces starch to shorter chains; beta amylase- reduces starch and short chains to maltose)
  - Stages of starch degradation:
    - Gelatinization- formation of long chain aqueous starch
    - Liquefaction- reduction of long starch chains to shorter molecules (reduces viscosity)
    - Saccharification- reduction of fermentable sugars
  - Mashing is affected by: temperature (rise in temperature controls amount of fermentable extract), time (influences yield and fermentability), mash pH (optimum range is 5.1-5.6), mash water (calcium is required), mash viscosity (thin mash favour the conversion of starch to sugars)
  - Fermentability and final concentration of alcohol are regulated by mash time and temperature
- Lautering (Wort separation)
  - The separation of wort from the converted mash, tun is predominant separation device (produces clear wort, obtain good extract recovery)
  - Mash is pumped to the false bottom of lauter tun which acts as a filtration system, rakes assist in leveling of grain bed and facilitates the filtration process

    - Separated wort continues to return to lauter tun until the bed is established and the wort is clear; once clear, wort is transferred to kettle; spent grain used as animal feed
- Kettle (wort boiling)
    - Functions to: inactivate enzymes, sterilize the wort, isomerize the hop components, remove un-wanted volatiles, precipitate proteins, concentrate wort by evaporation, form colour from Maillard reactions
    - Sterilization- destroys residual microorganisms
    - Protein precipitation- removes high molecular weight proteins, isomerization- produces alpha acid (hop flavour)
    - Dissipation of volatile constituents- dimethyl sulphide (DMS)
    - Additions:
        - Hops- bitter aroma based on timing of addition, multiple addition, hop extracts added as liquid
        - Adjuncts (syrup)- carefully added to kettle to increase extract
        - Salts- calcium as gypsum to reduce oxalate haze; copper to remove sulfur compound
    - Hot wort tank (whirlpool, tangential entry, protein precipitate spun into center of tank, clear wort sent to wort cooler)
    - Wort cooler ("paraflow", plate heat exchanger, reduces wort temperature to the initial fermentation temperature, where additional oxygen is added for yeast in fermenting)
- Fermentation
    - Depends on 3 parameters: wort composition (nutrients, oxygenation level, °P), yeast (proper pitching rate, viability), process conditions (temperature)
    - Yeast pitching:
        - In an average brewery, a large inoculum of cells is used
        - In each fermentation, cell density increases 3 to 4 fold
        - 1/3 to 1/4 of yeast crop in each fermentation is used to inoculate next batch
        - Excess yeast used as animal feed
        - Yeast pitching negates need to pitch inoculum, economic
        - Disadvantages: mutant generation, introduces contaminants, generates off favours in retarded fermentation, wash in 7.5% phosphoric acid
    - Yeast washing improves yeast quality by reducing bacterial contaminants (can use sterile water, acid wash with 0.75% ammonium persulphate, chlorine dioxide)
    - 4 pitches then introduce new yeast (craft brewers do 30+ pitches)

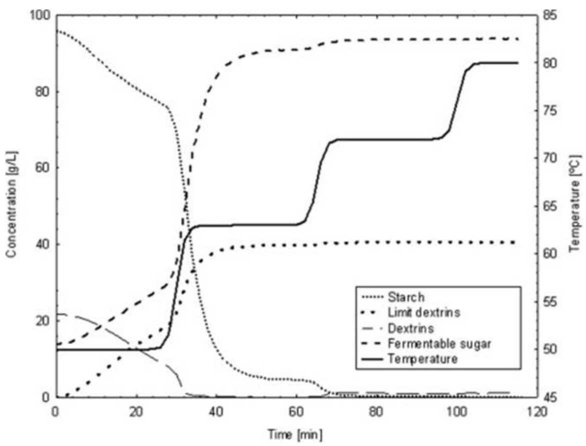

Figure 7: Temperature profile during mashing process

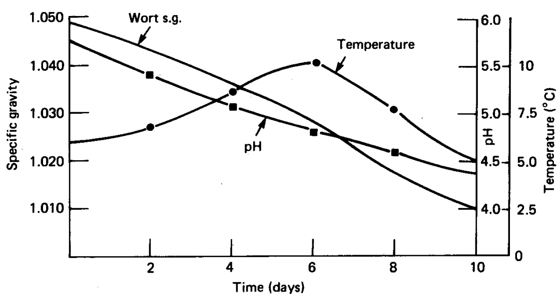

Figure 8: Lager fermentation. Low temperature to reduce by-product production

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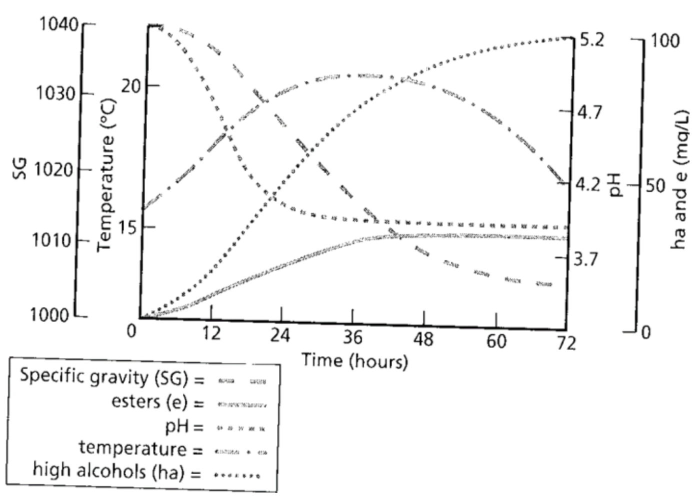

Figure 9: Ale fermentation to promote production of by-products to contribute to flavor. Temperature used to control fermentation rate. Residual sugars to add body and sweetness.

- End of fermentation: Diacetyl rest
    - High fermentation temperature leads to diacetyl formation
    - Diacetyl rest is when fermenter is held at a higher temperature to allow for yeast to reduce the diacetyl
    - 11 °C for 2-10 days towards the end of the fermentation

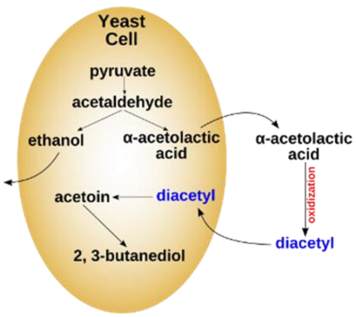

Figure 10: Diacetyl formation and re-assimulation

- Transfer to storage
    - Separate yeast – mature beer at 0 °C – precipitate proteins, remove oxalate Chillproofing agents added before filtration (silica gels, stabilizes/removes haze forming elements (proteins))
    - Differing packaging processes (Pasteurization- 60 °C for 5 minutes; sterile filtration; bottle fermentation- Belgian styles, wheat beers)

Beer defects

Symptom	Cause
High diacetyl	Low pitching rate, high fermentation temperature, inadequate diacetyl rest, infection by Pediococcus damnosus. Low FAN, can add acetolactate decarboxylase,
Acetic acid	Oxygen, acetic acid bacteria, wild yeast
Higher alcohols	Low pitching rate, high fermentation rate, low FAN, wild yeast contamination
Stuck fermentation	Low pitching rate, low fermentation temperature
Low flavor and body, yeasty notes	High pitching rate

Microbe	Effects on Fermentation	Turbidity	Ropiness	Off-flavors in beer
Wild Yeast	Attenuation	+	-	Esters, Fusel alcohols, phenolics, H_2S
Lactic acid bacteria		+	+	Diacetyl, acetic acid, lactate, acetoin
Acetic acid bacteria		+	+	Acetic acid
Enterobacteria	Slows, nitroso compounds	-	-	Fusel alcohols, DMS, acetic acid
Zymomonas		+	-	H_2S, acetaldehyde

Microbe	Turbidity	Ropiness	Off-flavors in beer
Pectinatus	+	-	H_2S, mercaptane, propionic,, acetic, lactic, succinic, acetoin
Megasphaera	+	-	H_2S, butyric, valeric, caproic and acetic acids. acetoin
Selenomonas	+	-	Acetic, lactic and proprionic acids
Zymophilus	+	-	Acetic and proprionic acids
Brevibacillus	-	+	
Clostridium	-	-	Butyric, caproic, propionic and valeric acids

- Design niches for biofilm formation includes dead-legs, welds, pitting and corrosion, poor drainage, gasket, and threaded pipes
- Sanitation hotspots include heat exchangers, sample valves and faucets, gaskets, pipe and hose lines, gas lines, kegs and filling heads
- The facility must contain sufficient drains, floors sloping uniformly to the drains, hard smooth walls, and non-absorbent food contact surfaces
- Standard Sanitation Operating Procedures must be put in place to provide a schedule for sanitation procedures, provide a foundation to support a routine monitoring program, encourage prior planning to avoid mistakes, identify trends and prevent recurrent problems, ensure everyone at plant understands sanitation, provide a constant training tool for employees, and lead to improved sanitation practices in the plant

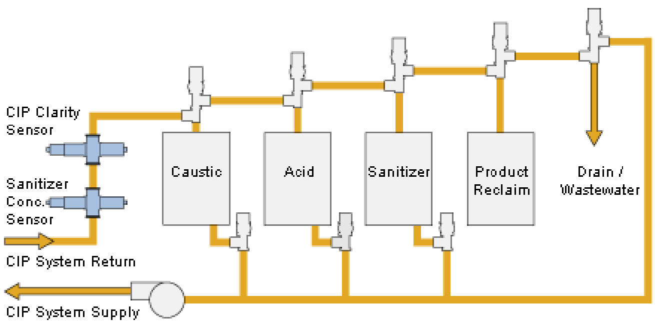

Figure 4: a diagram of the clean in place method

Manual cleaning methods	Clean-in-place methods
Dismantle equipment	In-situ cleaning with controlled cycles
Pads and brushes for scrubbing	Consistent results
Physical force applied	Rapid process
Cheaper than CIP	Reduced water/chemical consumption
Variable performance	Expensive
Scratching from excessive force	Minimal physical action required
Cross-contamination possible	Potential to miss hidden spots

Table 3: A comparison of various cleaning methods for brewing equipment