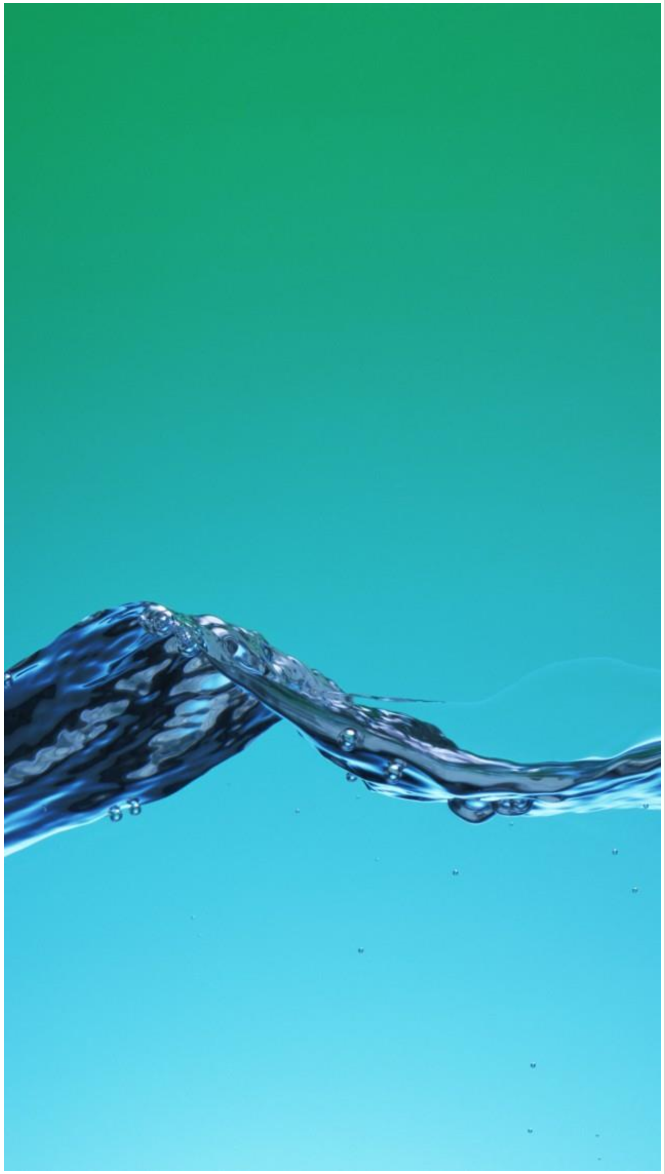
Water in Brewing: 101
An introduction.

Ian Johnson

January 31, 2020

DISCLAIMER

- No conflicts of interest
- I am only covering the basics. There is a lot more to each of these topics.
- I will give you some references at the end.



BACKGROUND

- Bachelor's Degree in Chemistry.
- Experience as a homebrewer and thus home brew experimenter.
- Avid reader of textbooks and journal articles.

BACKGROUND

I got interested in this topic because:

- I could not make a very good pilsner. It always came out tasting like a Dortmunder.

- I had no problems making a great porter.

- I read articles on how the water differed across major brewing cities.

PURPOSE OF THIS SESSION

At the end of this session, you should be able to:

- Discuss the importance of examining the water profile in making a particular style of beer.
- Discuss the importance of achieving the correct pH for the mash.
- Discuss some alternative ways to get the correct water profile for a particular style of beer.

FOUR MAIN MESSAGES

1. Need to assess your water relative to the style of beer you are brewing

2. Aim for a mash pH of approximately 5.4

3. Sulfates accentuates the hops - Chloride accentuates the malt

4. Crystal malt / Dark malts add acidity

WATER REPORT FROM THE CITY OF TORONTO

TORONTO

Drinking Water Analysis SUMMARY 2018

Drinking Water Analysis Summary for All Plants and Distribution for January 01 to December 31, 2018

	Units	AO/OG	MAC/IMAC	Sampling Date	Number of Samples	Reporting Limits	Number of Detectable Results	Max.	Min.	Avg.
Microbiological Parameters										
E. coli - Presence/Absence			A	1/01 - 12/31	11936		0	Absent	Absent	100.00% Absent
Ecoli - membrane filtration	CFU/100mL			1/01 - 12/31	168		0	0	0	0
Heterotrophic Plate Count	CFU/mL			1/01 - 12/31	11963		1529	7300	0	0.3
Total Coliform - Presence/Absence			A	1/01 - 12/31	11936		36	Present	Absent	99.7% Absent
Total Coliform - membrane filtration	CFU/100mL			1/01 - 12/31	168		10	4	0	0.1
Microcystin	µg/L		1.5	1/01 - 12/31	107	0.10	1	0.11	0	0.001
Operational Parameters										
Aluminum	mg/L	0.1		1/01 - 12/31	306	0.01	304	1.99	0	0.039
Fluoride	mg/L		1.5	1/01 - 12/31	1545	0.10	1545	1.05	0.21	0.66
Total Chlorine residual (Chloramines)	mg/L		3.0	1/01 - 12/31	6468	0.1	6466	2.5	0	1.69
Turbidity (Distribution only)	NTU	5		1/01 - 12/31	6408	0.1	6097	18.6	0	0.40
General Chemical and Physical Parameters										
Alkalinity	mg/L	30-500		1/01 - 12/31	116	1.6	116	96.5	82.7	90.3
Colour	T.C.U.	5		1/01 - 12/31	48		48	1	1	1
Conductivity	µmhos/cm			1/01 - 12/31	104	1.5	104	366	289	322
Hardness (as CaCO3 - calculated)	mg/L	80-100		1/01 - 12/31	110	1	110	133	121	128
pH		6.5-8.5		1/01 - 12/31	1222		1222	8.5	6.9	7.6
TOC	mg/L	5		1/01 - 12/31	64	1.0	64	2.7	1.5	2.1
Dissolved Solids (calculated)	mg/L	500		1/01 - 12/31	96	0.13	96	240	190	209
Inorganic Parameters										
Antimony	mg/L		0.006	1/01 - 12/31	40	0.00003	40	0.00040	0.00020	0.00021
Arsenic	mg/L		0.010	1/01 - 12/31	40	0.00005	40	0.0011	0.0004	0.0007
Barium	mg/L		1.0	1/01 - 12/31	40	0.0005	40	0.024	0.002	0.022
Beryllium	mg/L			1/01 - 12/31	40	0.00005	0	0	0	0
Boron	mg/L		5.0	1/01 - 12/31	40	0.005	40	0.026	0.013	0.024
Cadmium	mg/L		0.005	1/01 - 12/31	40	0.00001	14	0.00010	0	0.000006
Caesium	mg/L			1/01 - 12/31	40	0.00001	1	0.00002	0	0.000001
Calcium	mg/L			1/01 - 12/31	110	0.2	110	38.0	33.5	36.0
Chloride	mg/L	250		1/01 - 12/31	107	0.2	107	41.5	23.8	27.9
Chromium	mg/L		0.05	1/01 - 12/31	40	0.0002	40	0.0009	0.0002	0.0006

BREW.

WATER REPORT FROM THE CITY OF TORONTO

	Units	AO/OG	MAC/IMAC	Sampling Date	Number of Samples	Reporting Limits	Number of Detectable Results	Max.	Min.	Avg.
Cobalt	mg/L			1/01 - 12/31	40	0.00001	4	0.00001	0	0.000001
Copper	mg/L	1		1/01 - 12/31	272	0.0008	267	0.1560	0	0.0123
Cyanide (Free)	mg/L		0.2	1/01 - 12/31	16	0.003	0	0	0	0
Iron	mg/L	0.3		1/01 - 12/31	231	0.01	181	1.740	0	0.063
Lead	mg/L		0.010	1/01 - 12/31	323	0.00005	154	0.036	0	0.0005
Magnesium	mg/L			1/01 - 12/31	110	0.1	110	9.5	8.9	9.1
Manganese	mg/L	0.05		1/01 - 12/31	40	0.0005	10	0.0013	0	0.0002
Mercury	mg/L		0.001	1/01 - 12/31	19	0.00003	0	0	0	0
Molybdenum	mg/L			1/01 - 12/31	40	0.00003	40	0.0294	0.0010	0.0019
Nickel	mg/L			1/01 - 12/31	40	0.0002	40	0.0018	0.0002	0.0005
Nitrate	mg/L		10.0	1/01 - 12/31	107	0.01	107	0.55	0.15	0.39
Nitrite	mg/L		1.0	1/01 - 12/31	107	0.002	14	0.0040	0	0.0004
Orthophosphate	mg/L			1/01 - 12/31	1556	0.5	1554	4.5	0	2.2
Potassium	mg/L			1/01 - 12/31	107	0.05	107	1.7	1.5	1.6
Selenium	mg/L		0.01	1/01 - 12/31	40	0.0005	10	0.0006	0	0.00014
Silver	mg/L			1/01 - 12/31	40	0.00001	0	0	0	0
Sodium	mg/L	200		1/01 - 12/31	163	0.4	163	27.3	12.4	15.1
Strontium	mg/L			1/01 - 12/31	40	0.003	40	0.192	0.175	0.183
Sulphate	mg/L	500		1/01 - 12/31	107	0.2	107	28.3	20.7	25.1
Terbium	mg/L			1/01 - 12/31	40	0.00005	0	0	0	0
Thallium	mg/L			1/01 - 12/31	40	0.00005	0	0	0	0
Thorium	mg/L			1/01 - 12/31	11	0.00005	3	0.0001	0	0.00002
Tin	mg/L			1/01 - 12/31	40	0.0005	1	0.0006	0	0.00001
Titanium	mg/L			1/01 - 12/31	40	0.0002	40	0.0027	0.0013	0.0019
Tungsten	mg/L			1/01 - 12/31	40	0.00005	40	0.0002	0.0001	0.0001
Uranium	mg/L		0.02	1/01 - 12/31	40	0.00005	40	0.0004	0.0002	0.0003
Vanadium	mg/L			1/01 - 12/31	40	0.00005	40	0.0004	0.0001	0.0003
Zinc	mg/L	5		1/01 - 12/31	40	0.01	2	0.02	0	0.001
Disinfection Byproducts – Trihalomethanes										
Bromodichloromethane	µg/L			1/01 - 12/31	72	0.2	72	7.2	1.2	3.5
Bromoform	µg/L			1/01 - 12/31	72	0.2	53	0.7	0	0.26
Chloroform	µg/L			1/01 - 12/31	72	0.2	72	10.0	1.3	4.0
Dibromochloromethane	µg/L			1/01 - 12/31	72	0.2	72	4.1	1.1	2.3
THM (total)	µg/L		100	1/01 - 12/31	72	0.2	72	21.9	3.8	10.0
THM (total - end of line)	µg/L		100	1/01 - 12/31	13	0.2	13	17.2	4.7	10.4
Disinfection Byproducts- Haloacetic acids										
Bromoacetic acid	µg/L			1/01 - 12/31	59	0.9	0	0	0	0
Bromochloroacetic acid	µg/L			1/01 - 12/31	59	1.0	43	3.0	0	1.3
Chloroacetic acid	µg/L			1/01 - 12/31	59	2.0	0	0	0	0
Dibromoacetic acid	µg/L			1/01 - 12/31	59	1.20	2	1.8	0	0.05
Dichloroacetic acid	µg/L			1/01 - 12/31	59	0.5	59	4.5	0.5	2.0
HAA-5 (total)	µg/L			1/01 - 12/31	59	2.0	44	8.5	0	2.9
Trichloroacetic acid	µg/L			1/01 - 12/31	59	0.55	45	2.9	0	1.1

IMPORTANT IONS IN BREWING

Compound	Recommended level for brewing
Alkalinity	0 -100 ppm (expressed as carbonate)
Calcium (Ca^{2+})	50 - 150 ppm
Magnesium (Mg^{2+})	0-40 ppm
Sodium (Na^{+})	0-50 ppm
Sulfate (SO_4^{2-})	0 – 250 ppm
Chloride (Cl^{-})	0-100 ppm

Obviously, you don't want Arsenic, Lead, or other toxins.

Source: J Palmer, C Kaminski. Water, Brewers Publications, 2013

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IMPORTANT IONS IN BREWING

Compound	Recommended level for brewing	Levels in Toronto (Lake Ontario)
Alkalinity	0 -100 ppm (expressed as carbonate)	90.3 ppm
Calcium (Ca^{2+})	50 - 150 ppm	37 ppm
Magnesium (Mg^{2+})	0-40 ppm	9 ppm
Sodium (Na^{+})	0-50 ppm	15 ppm
Sulfate (SO_4^{2-})	0 – 250 ppm	25 ppm
Chloride (Cl^{-})	0-100 ppm	27 ppm

Source: J Palmer, C Kaminski. Water, Brewers Publications, 2013

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IMPORTANT IONS IN BREWING

Compound	Recommended level for brewing	Reverse Osmosis (RO) water
Alkalinity	0 -100 ppm (expressed as carbonate)	~0 ppm
Calcium (Ca^{2+})	50 - 150 ppm	~0 ppm
Magnesium (Mg^{2+})	0-40 ppm	~0 ppm
Sodium (Na^{+})	0-50 ppm	~0 ppm
Sulfate (SO_4^{2-})	0 – 250 ppm	~0 ppm
Chloride (Cl^{-})	0-100 ppm	~0 ppm

Source: J Palmer, C Kaminski. Water, Brewers Publications, 2013

LIST OF THE WATER CHEMISTRY FROM SOME FAMOUS BREWING CITIES (in milligrams per liter)

City	Calcium	Magnesium	Bicarbonate	Chloride	Sulfate
Pilsen	7	2	16	6	8
Dortmund	230	15	235	130	330
Munich	77	17	295	8	18
Dublin	120	4	315	19	55
London	70	6	166	38	40
Burton on Trent	275	40	270	35	610
Toronto	37	9	90	27	25

Source: J Palmer, C Kaminski. Water, Brewers Publications, 2013 and City of Toronto Drinking Water Report

PICK A BEER STYLE:
London Porter

City	Calcium	Magnesium	Bicarbonate	Chloride	Sulfate
London	70	6	166	38	40
Toronto	37	9	90	27	25

We don't need to do much to get it exactly the same.

- a bit low in calcium ions
- a bit lower in bicarbonate / alkalinity
- a bit lower in sulfate

How to handle it?

- could add a bit of gypsum (Calcium Sulfate) or just use it "as is".

PICK A BEER STYLE:
Pilsner

City	Calcium	Magnesium	Bicarbonate	Chloride	Sulfate
Pilsen	**7**	**2**	**16**	**6**	**8**
Toronto	37	9	90	27	25

Now, we have problems.

- Too much of everything.

How to handle it?

- Need to dilute the water with Reverse Osmosis (RO) water or start with RO water

WHY DO THESE IONS MATTER?

- Need to go into a bit of chemistry here.
- Let me know if it gets a bit too wild.

MAIN MESSAGE #2

- The goal is to aim for a pH of the mash to be around 5.4.

- Reason: improved function of enzymes
  improved flavour

So don't worry about the pH of your water supply, look at the alkalinity and focus on the mash pH.

AMYLASES

Name	Optimal temperature	Optimal pH
Beta amylase	60ºC to 65ºC (140ºF to 149ºF)	5.4 to 5.5
Alpha amylase	72ºC to 75ºC (151ºF to 160ºF)	5.6 to 5.8

Source: Kunze W, *Technology Brewing and Malting*. VLB Berlin, 1996

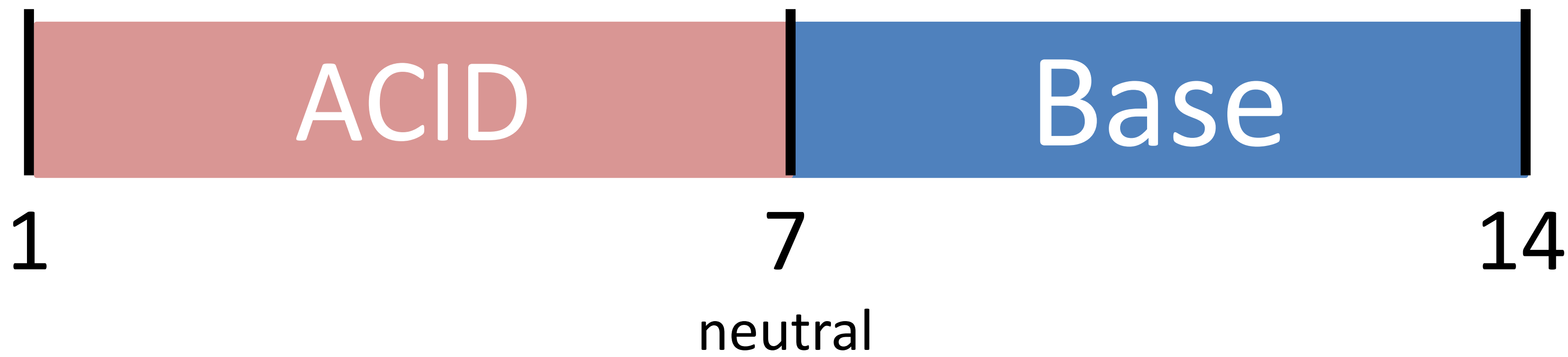
pH

pH - potential for Hydrogen

- measure of the acidity of a solution.

- Think of pH like temperature – a measure. It tells you the concentration of hydrogen ions you have in solution at a point in time.

pH



pH Scale

pH scale is a log scale.
pH 6 has 10 times more hydrogen ions than pH 7.
pH 5 has 100 times more hydrogen ions that pH 7.

ALKALINITY

Alkalinity is a measure of the resistance to changing the pH.

- that is: how much acid do you need to add to change the pH.

- a form of "buffering capacity"

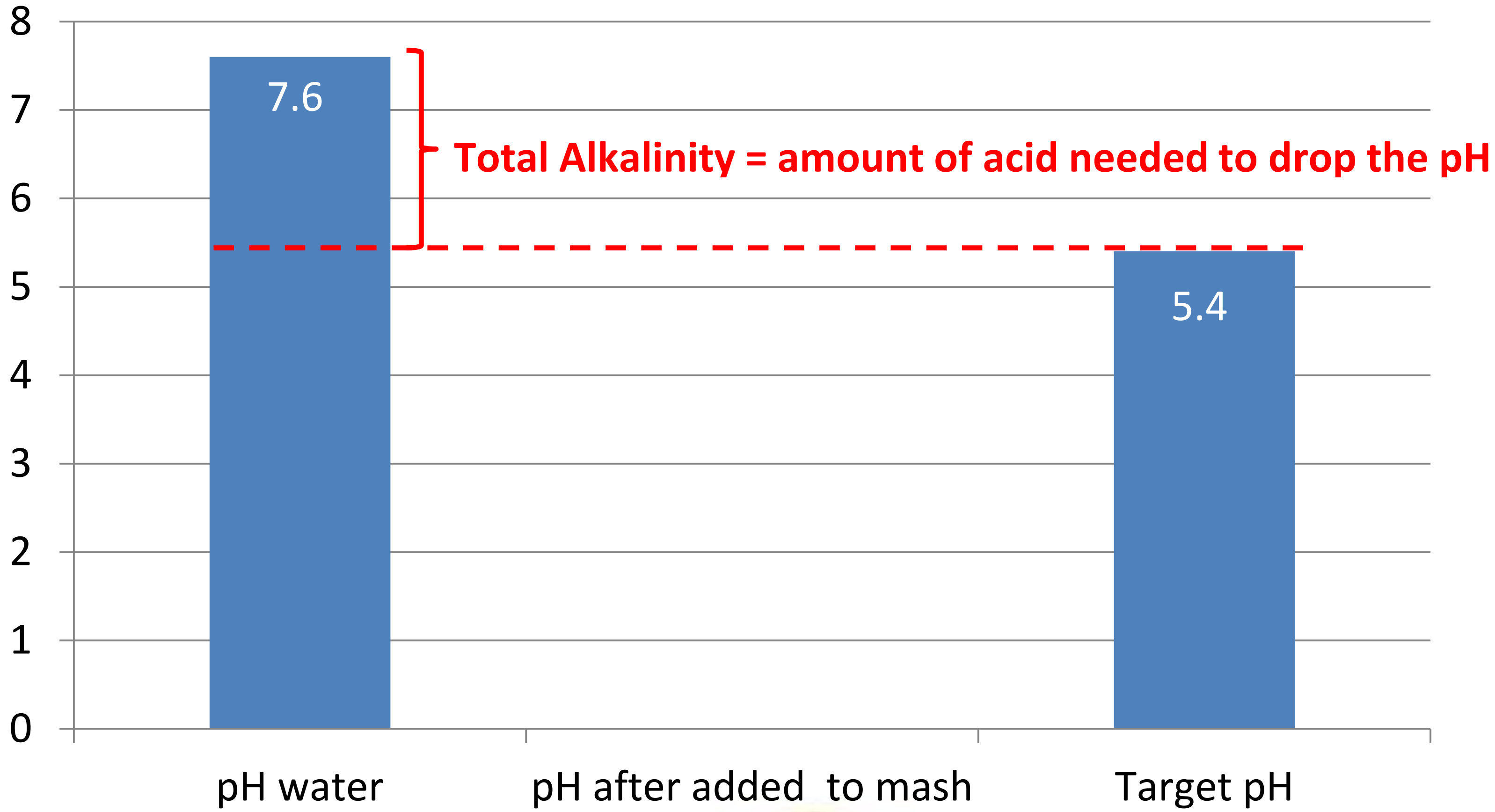
i.e. If you buy a buffer solution of 4.0 for your pH probe, it will strongly resist any change from that pH.

PH AND ALKALINITY

Total Alkalinity

- is the resistance to changing the pH in the water to a predetermined pH before you add the grains.

GRAPH OF TOTAL ALKALINITY



ADDING MALT TO THE WATER IN THE MASHTUN

Calcium ions in the water

react with

phosphates that are present in the malt

↓

a complex crystal

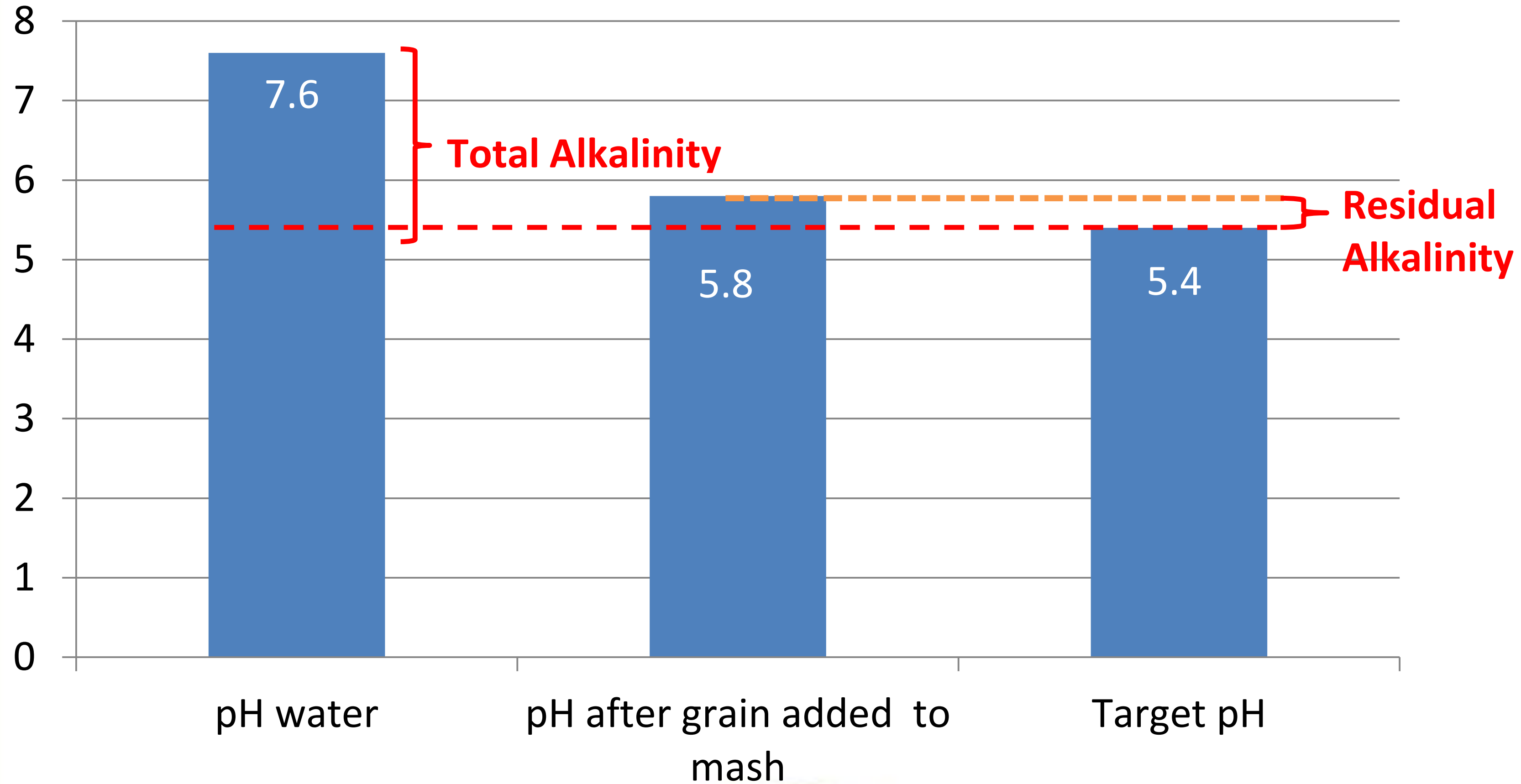
and

acid

PH AND ALKALINITY

Residual Alkalinity is the resistance to changing the pH in the mash to the same predetermined pH after the grains have been added.

GRAPH OF TOTAL VERSUS RESIDUAL ALKALINITY



IMPLICATIONS

- Pilsner and pale malts are the least acidic of the malts. Using them in lower quantities (e.g. sessional ales or light lagers) will add less acid. It may not be enough to overcome the natural alkalinity in the water.

- You may need to decrease the pH (e.g. create more acid or more calcium) to reach the ideal pH.

IMPLICATIONS

- **Let's return to the water profiles of different cities and look at the balance between Calcium levels and Bicarbonate levels.**

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IMPLICATIONS

- **What about Burton on Trent?**

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IMPLICATIONS

- What about Burton on Trent?

- Calcium and Bicarbonate levels are relatively balanced.

- For me in Toronto, adding Calcium Sulfate (Gypsum) will rebalance the Calcium and the Bicarbonate plus add some sulfate.

MAIN MESSAGE #3: SULFATES ACCENTUATES THE HOPS - CHLORIDE ACCENTUATES THE MALT

- When adding calcium to brewing water, you have three options:
  1. Add Gypsum ($CaSO_4$) to accentuate the hop character.
  2. Add Calcium Chloride ($CaCl_2$) to accentuate the malt.
  3. Combination of the two.

It all depends on which flavours you want to accentuate.

LET'S GO BACK TO THE London Porter

City	Calcium	Magnesium	Bicarbonate	Chloride	Sulfate
London	70	6	166	38	40
Toronto	37	9	90	27	25

What is the balance of Calcium and Bicarbonate in London's water?

Answer: more Bicarbonate.

So why does it work for a porter?

MAIN MESSAGE #4: CRYSTAL MALT / DARK MALTS ADD ACIDITY

- In their kilning, crystal malts and dark roasted malts create various melanoidins which are acidic.
- Adding crystal and dark malts will help reach a mash pH of 5.4
- This is why I had no problem making porters, particularly as I prefer to add quite a bit of crystal malt to my porters to get a depth of flavour.

ALTERNATIVE TO DARK MALTS OR ADDING MORE CALCIUM: – ADD ACID

Adding acid or acidulated malt.

- **Commonly used one is 88% lactic acid or use some acidulated malt.**
- **Reacts with bicarbonate (HCO_3^-) to create carbon dioxide. Leaves calcium levels unaffected.**
- **Avoid acetic acid or vinegar since it gives an off-flavour (unless you are making a Lambic beer).**

DEALING WITH ALKALINITY – SPARGE WATER

Adding acid or use treated RO water.

- This process can also be applied to the sparge water so it will not affect the mash pH and keep a low wort pH.

- Do not have to go all the way to pH 5.4 since the mash will act as a buffer (resist rising). So decreasing the pH a bit should be fine.

SUMMARY: PUTTING IT ALL TOGETHER - THINK FIRST

Some questions to consider:

- What style of beer do I want?
- What flavour profile do I want?
- What is the chemical profile of my available water supply?
- Do I need to worry about alkalinity? (light beer versus dark one, sessional versus higher strength).
- How do I create or adjust the water profile so it will work with my combination of malts and hops?

DID I ACHIEVE THE PURPOSE OF THIS SESSION?

At the end of this session, you should be able to:

– Discuss the importance of examining the water profile in making a particular style of beer.

– Discuss the importance of achieving the correct pH for the mash.

– Discuss some alternative ways to get the correct water profile for a particular style of beer.

FOUR MAIN MESSAGES

1. Need to assess your water relative to the style of beer you are brewing

2. Aim for a mash pH of approximately 5.4

3. Sulfates accentuates the hops - Chloride accentuates the malt

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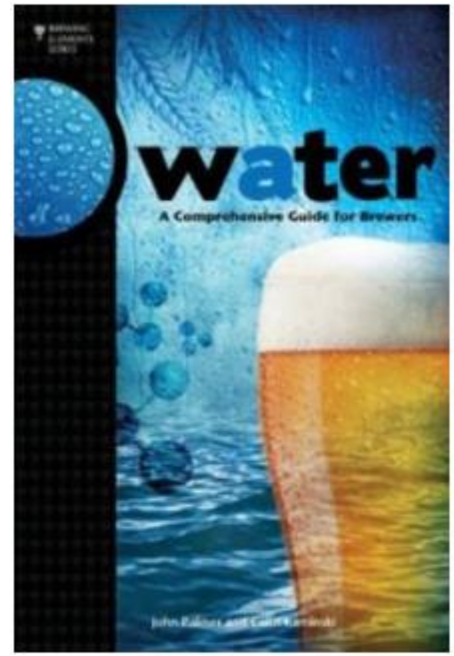
THANK YOU.

QUESTIONS AND DISCUSSION

REFERENCES

- J Palmer, C Kaminski. *Water*, Brewers Publications, 2013

- Beechum D, Kohn D. Simple Water Adjustment. *Zymurgy* 2019, May/June issue.



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CHLORINES AND CHLORAMINES

- Used to disinfect the water distribution system especially between when the water leaves the treatment plant and comes out your tap.

- Problem is that they can react with chemicals in the malt to make chlorinated by-products that have off flavours.

CHLORINES AND CHLORAMINES

- Chlorine is easy to remove. It is a gas so heating the water before the mash and leaving it uncovered for a few minutes should remove most of it.

- Chloramines are more challenging. They are dissolved in the water.
  - Removed by adding a half or whole Campden (metabisulfite) tablet. It changes the chloramines into chlorine which is removed by heat (as above). In the process, the metabisulfite turns into sulfate (which remains dissolved in the water).
  - Since metabisulfite is used as a preservative, some people aim for using the minimum possible so it does not affect the yeast.

BASIC CONCEPTS

- Chemical Equilibrium.
  - Chemicals are always in balance.
  - Use the example of H_2O & CO_2, H_2CO_3, and HCO_3^-

$$H_2O + CO_2 \rightleftarrows H_2CO_3 \rightleftarrows H^+ + HCO_3^-$$

  - In any solution, the amount of chemicals in each form is balanced.

BASIC CONCEPTS

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    Can you guess what will happen?

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  - In any solution, the amount of chemicals in each form is balanced.
  - Implication: If one heats the water so the carbon dioxide (CO_2) is driven off, : *Amount of carbonic acid drops and amounts of both hydrogen and bicarbonate ions will drop.*