Brew Master 9000
Hardware
Research and reference

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WB3.NO

The U.S. customary units should have been aborted

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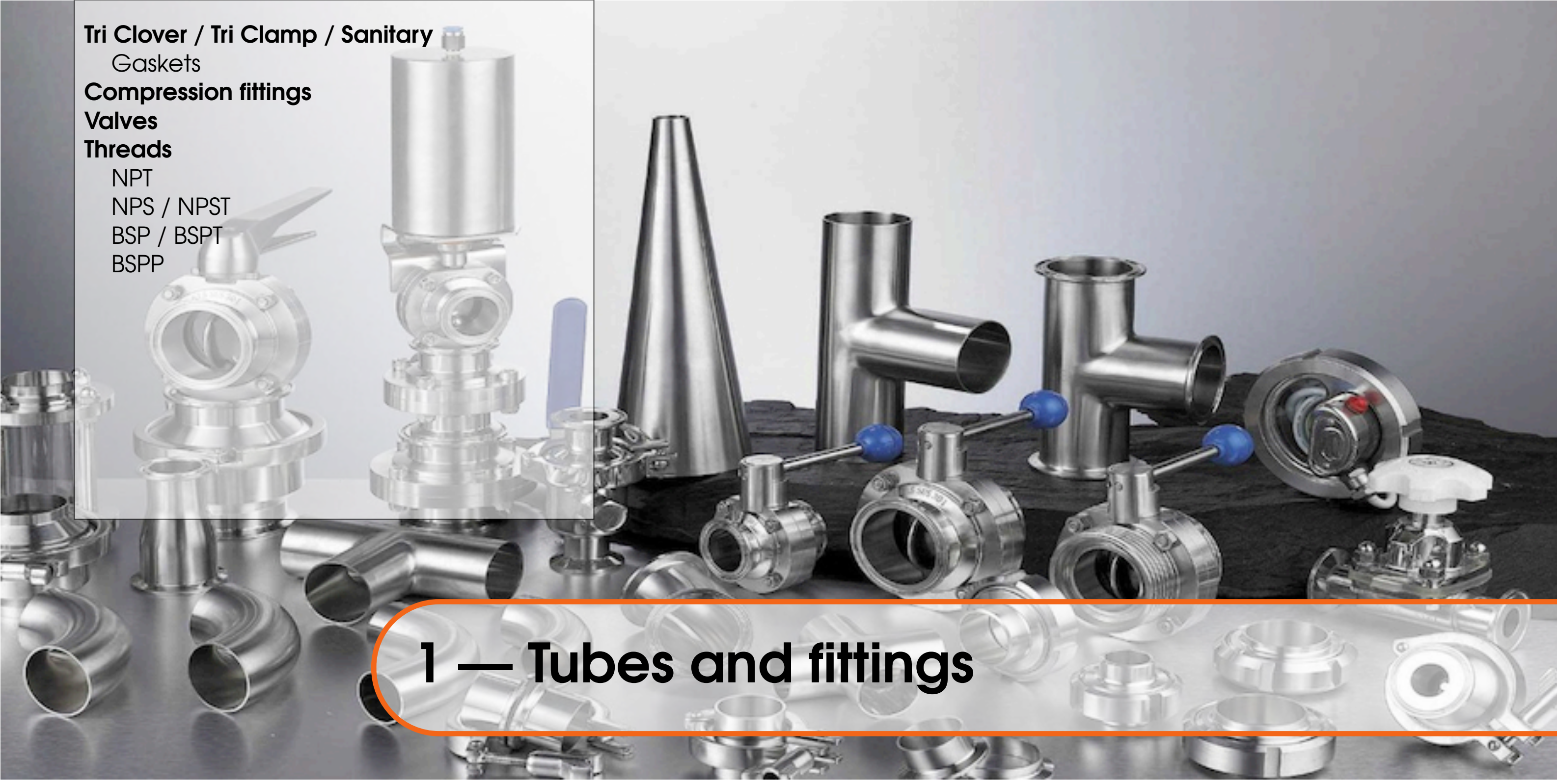
Part I

Theory



1 — Tubes and fittings

1.1 Tri Clover / Tri Clamp / Sanitary

These fittings are used throughout the brewing system as they provide easy dissassembling and just look really, really cool.

They consist of two flanges and a gasket that are compressed together with a clamp. The clamp is tightened with a thumb screw.

1.1.1 Gaskets

There are many types of gaskets produced for use with tri clamp fittings. Three of these types are commonly used in amateur brewing systems; silocone, EPDM (ethylene propylene diene monomer) rubber and PTFE (polytetrafluoroethylene) teflon.

Silicone

Temperature rating of $-49°C$ ~$230°C$.
These are the most common gaskets that are available. They will degrade over time if used with strong acids. As they stick very well to metal and are soft, they provide an excellent seal.

EPDM rubber

Temperature rating of $-34°C$ ~$149°C$.
They have better chemical resistance than silicone gaskets and will last longer than silicone gaskets. As the name implies they are made of rubber and are therefor soft and somewhat sticky.

PTFE teflon

Temperature rating of $-73°C$ ~$260°C$.
They have the best chemical resistance of all gaskets and will last the longest. They are, however, hard and will need considerably more compression to provide a good seal.

Gaskets with flanges

A normal gasket will fall right of the fitting when loose. If the gasket has a flange that covers the outer part of the fitting it will stay on the fitting when dissassembling (i.e. does not fall into the warm wort).

Stiffness

A stiff gasket that is not sticky will allow you to turn the fitting without dissassembling the entire connection. Stiffer gaskets will need more compression to provide a good seal.

1.2 Compression fittings

Compression fittings consists of a compression nut and ring that slides over the tube and a threaded fitting. If the tube is made of soft metal there should also be a support insert that is inserted into the tube to prevent it from collapsing.

These fittings should not be over tightened as this will ruin the compression ring and therefore the seal.

1.3 Valves

Any normal ball valve will work in a brewing system. Only full port ball valves have the same size hole in the ball as the pipeline.

It should be possible to dissassemble the valves for cleaning and repair. Therefore 3-part valves are recommended for a brewing system.

1.4 Threads

It is recommended to not combine threads of different types. A NPT male fitting will fit a BSPT female fitting, but will not make a seal.

1.4.1 NPT

NPT stands for National Pipe Taper. The threads are tapered so that they ”mash” together and form a seal.

1.4.2 NPS / NPST

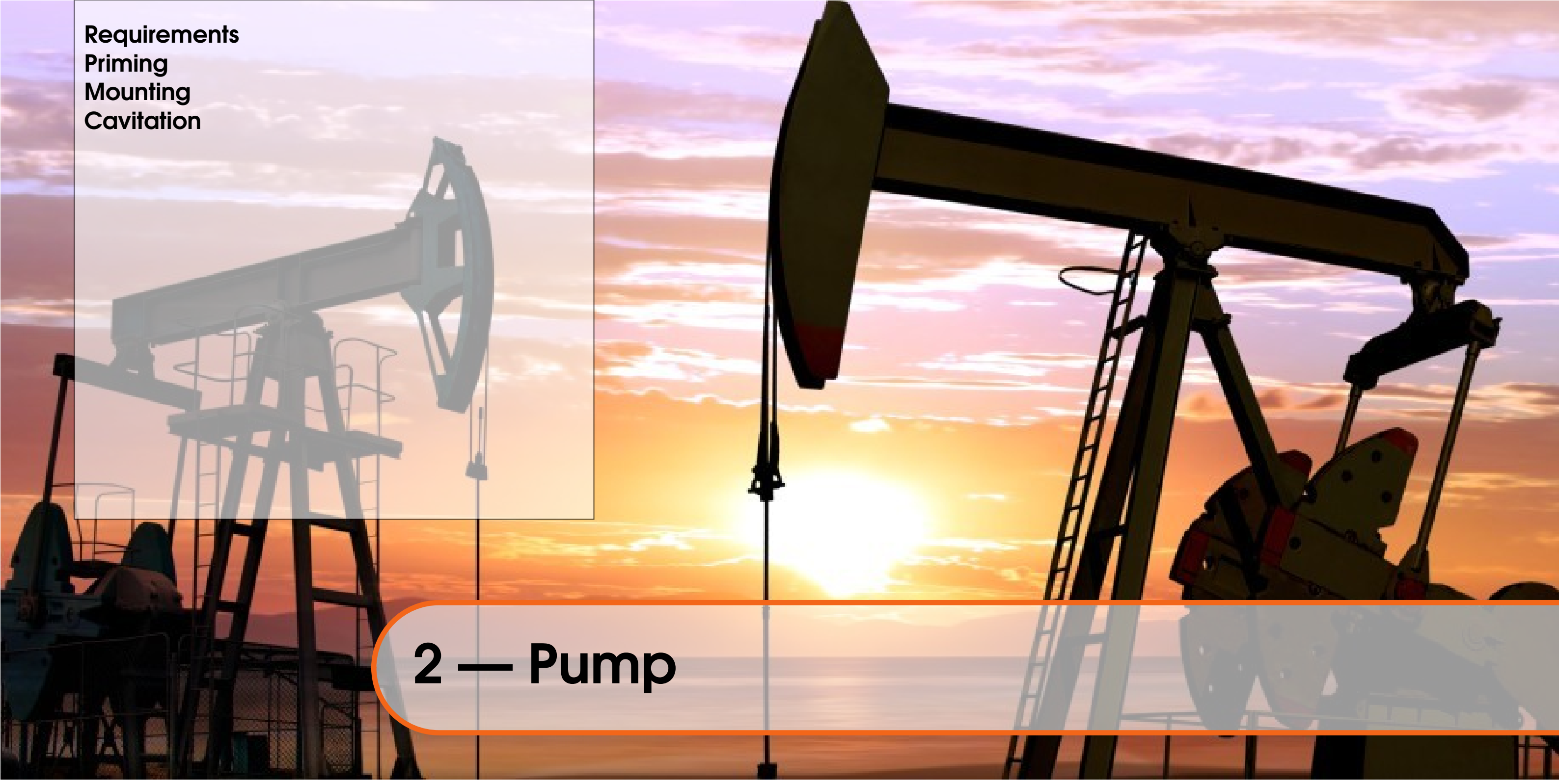
NPST stands for National Pipe Straight Thread. Unlike NPT the threads are straight and an O-ring or tape is needed to make a seal.

1.4.3 BSP / BSPT

BSPT stands for British Standard Pipe Thread. These threads are also tapered.

1.4.4 BSPP

BSPP stands for British Standard Parallel Pipe. Unlike BSP the threads are straight and an O-ring or tape is needed to make a seal.



2 — Pump

2.1 Requirements

A suitable pump for a brewing system have the following requirements

- All parts have to be of food grade.
- It should be magnetic coupled so that in the event of the impeller becoming stuck due to malt particles, the motor will not burn out.
- The lift limit should be more than the height of the brew stand.
- The temperature rating should be at least that of boiling wort (100°C).
- It should be self-priming.

2.2 Priming

Priming is to fill the pump head with the liquid that is to be pumped. As the pump is stored dry, the contents of the pump head is only air. As air and water have very different physical properties, a pump that is designed to pump a liquid will perform terrible at pumping air and will eventually break.

A self-priming pump differs from a non-priming pump that it can pump a mixture of air and liquid. This means that the pump will be able to remove air trapped in the head as long as it has a source of liquid.

A pump made to pump liquid should **never be run dry**.

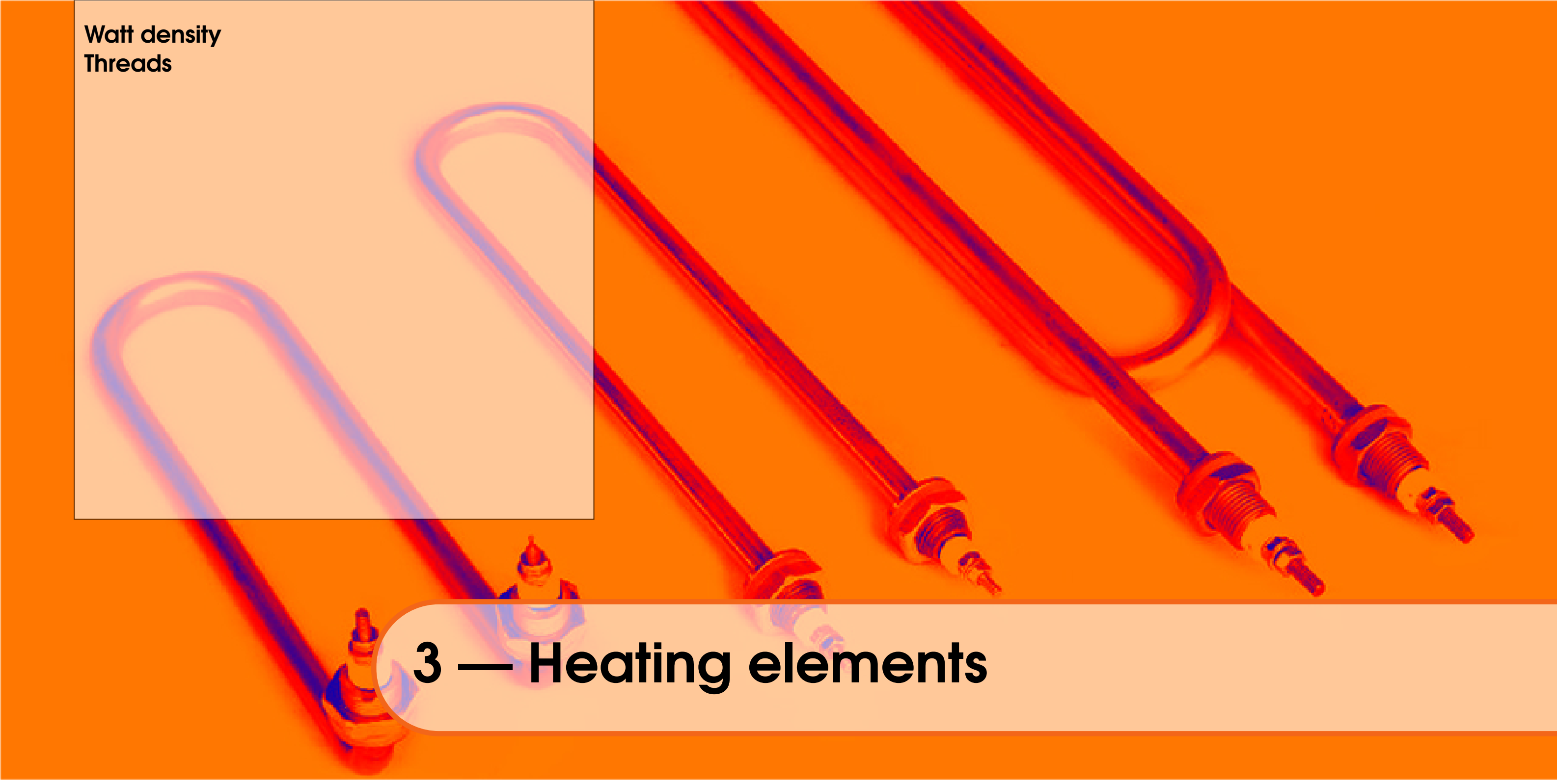
2.3 Mounting

The pump should be mounted so that liquid enters at the bottom of the head and exits at the top. This is to prevent air pockets from occupying the head. If the pump has to be mounted in a vertical position the head should be placed at the top, not the bottom.

Many pumps require that there is pressure at the inlet. Therefore it should be mounted as far as possible below the source of liquid.

2.4 Cavitation

Cavitation is the formation of vapor cavities in a liquid due to pressure differences around the impeller as it turns quickly and with great force. It can be harmful to the pump and will produce a rattle-like sound.



3 — Heating elements

3.1 Watt density

Heating elements comes in different watt density ratings. These are

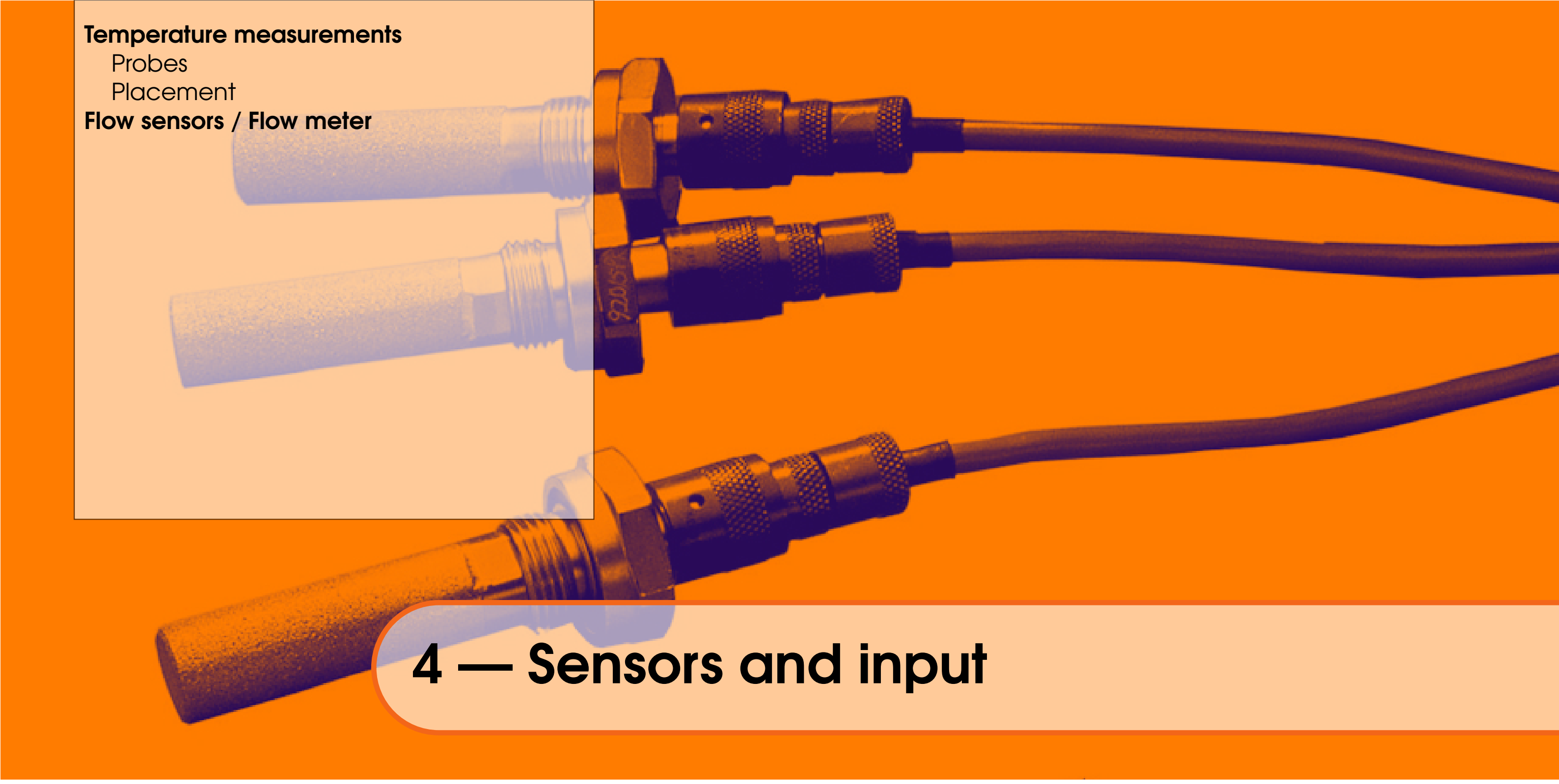
- Ultra Low Watt Density (50W per square inch)
- Low Watt Density
- Medium Watt Density
- High Watt Density

If the watt density is too high the wort will be scorched. Also, elements with lower watt densities tend to last longer.

A typical, recommended max value for hot water heaters is 75W per square inch.

3.2 Threads

The standard thread for american heating elements is the 1" NPT.



4 — Sensors and input

4.1 Temperature measurements

4.1.1 Probes

There are many different temperature probes available that either communicates digitally or outputs an analog signal that can be processed for use with various microcontrollers. The most common types seem to be

- DS18B20 (digital, Dallas 1-wire)
- LM35 (analog, 0-1V)
- Thermocouple (analog, needs amplifier)

The DS18B20 and LM35 are quite easy to use but lacks good casings for wet use. Thermocouples are the industry standard for temperature measurements and comes in a great number of different casings. They consist of two different types of conductors that provide a voltage difference according to the temperature of the system. This voltage difference is in the order of microvolts and an amplifier is needed to read the output.

DS18B20

The DS18B20 comes in a standarized TO-92 packaging. It communicates over the Dallas 1-wire bus that enables several sensors to share a dataline. They can also source power from the dataline so that only two wires are needed for the entire sensor-array. The temperature range of this sensor is $-55°C$ ~$125°C$ and it provides an accuracy of $\pm$ 0.5°C in the $-10°C$ ~$85°C$ range.

Thermocouples

Thermocouples consists of two conductors that differ in physical properties. When these two conductors contact each other they produce a voltage proportional to the temperature difference.

The main dissadvantage of thermocouples is that a system error of less than one degree Kelvin is difficult to achieve.

K-type thermocouple and amplifier

This seems to be the most common probe of the thermocouples types. It consists of chromel-alumel conductors. The temperature range of the probe can be as wide as $-200°C$ ~$1350°C$.

The MAX31855 is an amplifier for thermocouples produced by Maxim Integrated. It outputs an analog signal and requires an ADC for use with a microcontroller (or a microcontroller with an integrated ADC). There are libraries available for the Ardunio and the Raspberry Pi.

4.1.2 Placement

Liquid that is being heated does not have uniformly distributed temperature. There should be two probes per tank, and the average of the two will be the actual temperature of the system. If only one probe is used to measure the temperature of a tank the probe should be fitted at the middle (why?).

4.2 Flow sensors / Flow meter

A flow sensor can essensially be as simple as a fan that is rotated by the moving liquid. A magnet on the fan axel moves past a magnetic sensor and produces an electronic pulse on the output line. A microcontroller then records these pulses and is able to calculate the volume of liquid that has passed through the sensor.

These simple flow sensors comes in different volume per time ratings.

5 — Relays and heatsinks

5.1 Electromechanical relays

Electromechanical relays operate by an electromagnet that mechanically moves a conductor.

These need a flyback diode in parallel with the coil to prevent the controlling circuitry from damage when the relay is turned off and the magnetic field stored in the coil collapses.

5.2 Solid state relays

Solid state relays (SSR's) differ from electromechanical relays in that they have no moving parts. The switching-action is provided using semiconductors. The number of switches a SSR can withstand is much much greater then that of an electromechanical relay.

SSR's can also be switched so often they can provide a semi-correct power control of heating elements.

5.2.1 Zero crossing

Zero crossing means that the relay switches from the conducting to the non-conducting phase when the AC sine wave reaches the zero crossing point. This reduces the surge current through the load and greatly improves the lifespan of the SSR.

5.2.2 Calculating heatsink requirements for SSR

SSR's generally produce about 1W of heat for every ampere of the load.

5.2.3 Thermal pads and compound

Thermal pads or thermal compound should always be used when connecting a SSR to a heatsink.

As tiny irregularities in the flat, metal surface of the SSR and heatsink provide trapped air and thus insulation, thermal pads or compound is used to fill in these irregularities. If compound is used, only a very thin film is necessary to provide good thermal conductivity.

6 — RIMS-tube

6.1 What is RIMS

RIMS stands for Recirculating Infusion Mash System.
The wort is recirculated continously through the malt. The RIMS-tube contains a heating element and a temperature probe that enables the brewer to do step mashing by pumping the wort through the tube. RIMS also provides crystal clear wort as the wort is filtered throughout the entire mashing process.

6.2 Components

A typical RIMS-tube consists of the following

- Two tee's
- A heating element adapter and heating element
- A temperature probe adapater and temperature probe
- Two hose/pipe connections

7 — Tanks, vessels and kettles

7.1 Volumes

The following equations for volumes do not take into consideration other objects in the tanks, such as filters and stirrers. They instead give the minimum volume of the containers. Headspace and other objects should also be included in the final volume of the tanks.

7.1.1 Hot Liquor Tun (HLT)

This tank provides hot water for the mash and sparge. It has a heating element installed in the tank and uses the RIMS-tube for additional power when heating the mash water.

It's volume should be at least that of the needed mash water for the brew. This is calculated as follows

$$V_{HLT} = m_{malt} \cdot d_{malt} \cdot \frac{379}{400} \tag{7.1}$$

Where d_{malt} is the thickness of the malt and is generally set to 2.61 $\frac{L}{kg}$.

7.1.2 Mash/Lauter Tun (MLT)

This tank is where the malt is mashed at a constant or several, precise temperatures (step mashing). To keep the temperature constant, or to rise the temperature, the wort is passed through the RIMS-tube which heats the wort. The tank should also be very well insulated.

It's volume is calculated as follows

$$V_{MLT} = m_{malt} \cdot (0.67 + d_{malt}) \tag{7.2}$$

7.1.3 Boil Kettle (BK)

This tank is where the wort is boiled with the addition of hops. It has two heating elements installed in the tank and has an outlet to a chiller.

It's volume should be that of the wort produced for pre-boil and as a rule of thumb have a 20% head room to compensate for foam and splash.

$$V_{wort,pre-boil} = \frac{V_{beer} + V_{hops,absorbed}}{0.96} \cdot \frac{1}{k_{evap}} \tag{7.3}$$

Where k_{evap} is the evaporisationcoefficient which is based on the power from the heating elements and the surface area of the top of the kettle. It is generally set to 0.95. $V_{hops,absorbed}$ is the volume of wort that is absorbed by the hops and is dependent on the amount of hops. 100g of hops will probably absorb 1L of wort.

The total volume of the boil kettle should then be

$$V_{BK} = V_{wort,pre-boil} \cdot 1.2 \tag{7.4}$$

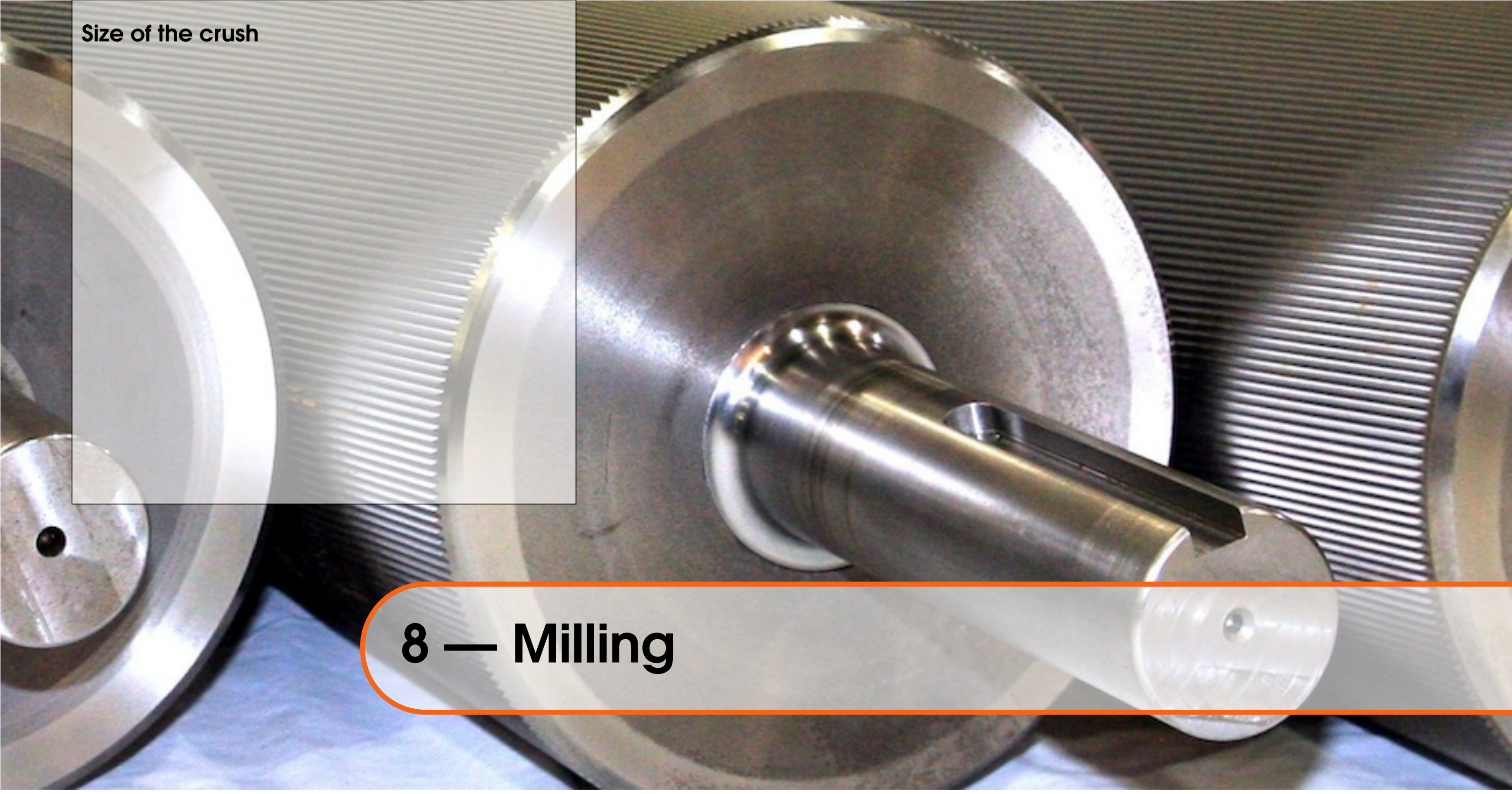
7.2 Insulation

The formula for calculating the heat loss of a completely insulated vessel is

$$H = \frac{A(T_h - T_c)}{R} \tag{7.5}$$

Where A is the surface area of the tank, T_h is the temperature of the liquid in the tank and T_c is the temperature of the surroundings. R is a unique value for the insulation material, where a higher R-value designates better insulation properties.

Many insulation materials are based on trapping air in the material. Air is a very bad conductor of heat, and therefore the material insulates heat transfer. These insulation materials perform worse if they are compressed, as they can not trap enough air.

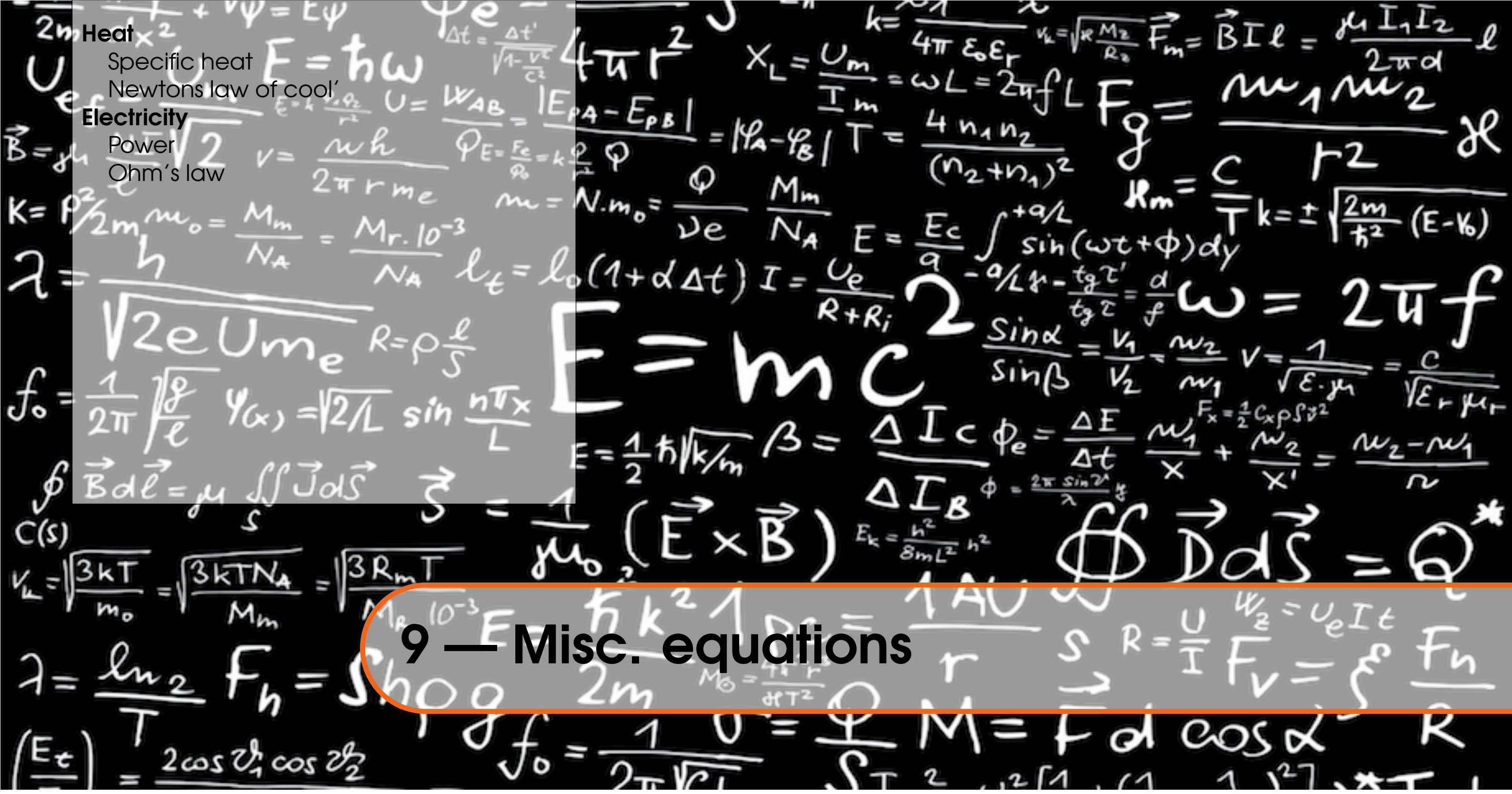


8 — Milling

8.1 Size of the crush

Grains with a husk should be crushed so that the husk is mosly intact. The husk aids in filtering of the wort and a too fine crush can make the filter stuck.

Wheat does not contain a husk. It is also a grain that is hard to efficiently extract sugars from without the grain being crushed much finer than other grains.



9 — Misc. equations

9.1 Heat

9.1.1 Specific heat

Specific heat is the amount of heat per unit mass required to raise the temperature by one degree Kelvin (without a change of phase).

$$Q = cm\Delta T \tag{9.1}$$

Where Q is the heat added, c is the specific heat of the material, m is the mass of the material and ΔT is the change in temperature.

Exercise 9.1 How fast will we be able to heat 120L of water from 10°C to 67°C if we have available 6kW of heat?

Solution

6kW = $6000\frac{J}{s}$

$c_{H_2O} = 4.18 \cdot 10^3 Jkg^{-1}K^{-1}$

$$t = \frac{4.18 \cdot 10^3 Jkg^{-1}K^{-1} \cdot 120kg \cdot (67°C - 10°C)}{6000\frac{J}{s}}$$

$$t = 4765.2s = 79.42min$$

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9.1.2 Newtons law of cool'

Newton's law of cooling states that if the temperature changes are small enough, the temperature of an object after a certain time can be calculated as follows

$$T(t) = T_s + (T_0 - T_s)e^{-kt} \tag{9.2}$$

Where T(t) is the temperature of the object at time t, T_s is the temperature of the surroundings, T_0 is the initial temperature of the object and k is a constant that is unique to the system.

9.2 Electricity

9.2.1 Power

Power is measured in watts and is proportional to the voltage and current

$$P = V \cdot I \tag{9.3}$$

9.2.2 Ohm's law

Ohm's law states that the current through a conductor is directly proportional to the voltage provided and the resistance of the conductor.

$$I = \frac{V}{R} \tag{9.4}$$

Exercise 9.2 A heating element is sold as 3000W at 240V. How many watts will it provide if the voltage is 230V?

Solution

Find the resistance of the nichrome wire in the element

$$I = \frac{P}{V} = \frac{3000W}{240V} = 12.5A$$

$$R = \frac{V}{I} = \frac{240V}{12.5A} = 19.2\Omega$$

Then calculate current and power using the resistance

$$I = \frac{230V}{19.2\Omega} = 11.98A$$

$$P = V \cdot I = 230V \cdot 11.98A = 2755W$$

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Part II

Practice

10 — Materials List

Items without a listed price where scrapped from the bin or sourced for free.

Many of these items are purchased in larger lots than necessary, as smaller lots could not be found.

10.1 RIMS-tube

Article	Quantity	Price / $	Shipping / $	Total / $
Sanitary tee, Ø51mm pipe Ø64mm ferrule	2	34.00	16.00	50.00
Sanitary end cap, Ø64mm	2	6.18	3.74	9.92
2" sanitary EPDM gasket, flanged	8	12.00	-	12.00
2" sanitary PTFE gasket	6	12.00	-	12.00

Table 10.1: RIMS-tube materials list

10.2 Electronics

Article	Quantity	Price / $	Shipping / $	Total / $
ATMega328p	1	-	-	-
Capacitor, 33 μF electrolytic	10	0.99	-	0.99
Capacitor, 0.47 μF mylar	50	1.00	2.00	3.00
Capacitor, 100nF ceramic, SMD	50	2.35	-	2.35
LM3940, SMD	5	3.74	-	3.74
USB-B PCB headers	10	1.60	-	1.60
Screw terminals DZ39	50	9.50	-	9.50
12mm 3 pin DIN connector, screw type	10	21.00	-	21.00

Table 10.2: Electronics materals list

10.3 Bench

Article	Quantity / m	Price / NOK	Total / NOK
Two by four	4x4.2 = 16.8	-	-
Four by four	1x4.5 = 4.5	0.99	0.99
Row, 48x48mm	2x3.6 = 7.2	1.00	3.00
Plank, 19x148mm	2x5.2 = 10.4	2.35	2.35

Table 10.3: Bench materals list

10.4 Tanks

Article	Quantity	Price / $	Shipping / $	Total / $
OSO brand 200L hot water tank	1	-	-	-
OSO brand 300L hot water tank	1	-	-	-
Sanitary flange, Ø102mm pipe Ø115mm ferrule	2	19.98	-	19.98
Sanitary clamp, fits Ø115mm ferrule	2	37.98	-	37.98
Sanitary end cap, fits Ø115mm ferrule	2	19.98	-	19.98
4" sanitary PTFE gasket	1	4.49	-	4.49
4" sanitary EPDM gasket, flanged	2	4.49	-	4.49

Table 10.4: Tanks materals list

11 — Woodworking

11.1 Renderings

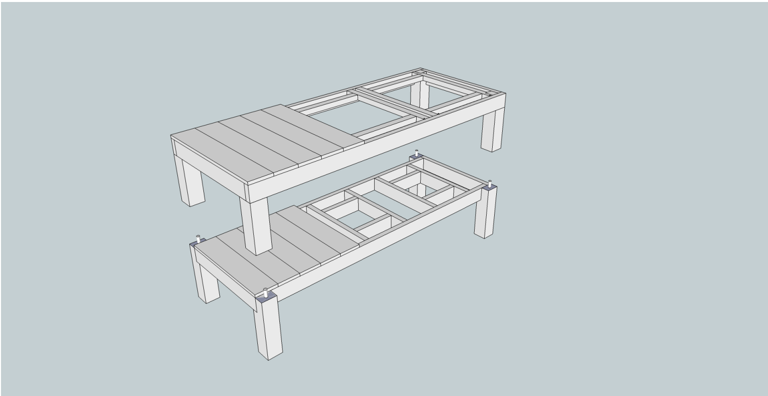

Figure 11.1: Bench, above

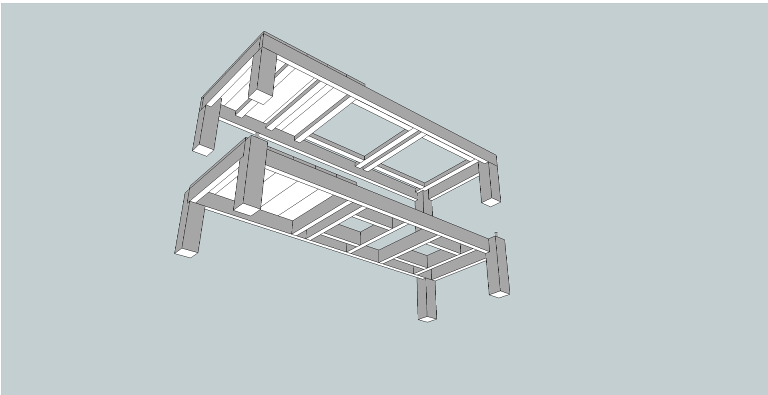

Figure 11.2: Bench, below

11.2 Sizes

The bench is 80cm tall, 80cm deep and 200cm wide. The feet are cut 2x40cm long.

11.3 Considerations

11.3.1 Transportation

It should be easy to transport the bench. As it is very heavy, it is divided into two parts that each can be transported on the roof of a car. The parts of the bench will be assembled together using metal rods, according to figure 11.1.

11.3.2 Surface treatment

The wood will have to be treated so that it can withstand spills of boiling wort.

12 — Metalworking

12.1 Tanks

All tanks are made from OSO brand hot water tanks (1977-1990 model). These come with a 50mm threaded hole for a heating element. The bottom parts of the tanks have feet.

There are adapters available to reduce the 50mm hole to a standard 1" threaded hole.

The system is sized to accomodate brewing 120L of finished beer using 48kg of malt.

12.1.1 HLT

The HLT is cut for a volume of 130L.

It is the bottom part of an OSO brand tank and has one heating element and feet. A $\frac{1}{2}$" hole is drilled in the bottom for draining water. There is a $\frac{1}{2}$" inlet on the side for return from the RIMS-tube.

12.1.2 MLT

The MLT is cut for a volume of 170L.

It is the top part of an OSO brand tank and has no feet. The inlet on the side is plugged with a male, threaded pipe cap.

12.1.3 BK

The BK is cut for a volume of approximately 190L

It has feet and two heating elements. The second element is mounted as a weldless fitting.

12.1.4 Initial cleaning

The tanks are initially cleaned using diluted hydrochloric acid. This is then neutralized using dilute sodium bicarbonate to prevent the acid from etching the steel. The procedure efficiently removes calcium and iron salts.

Further cleaning is performed using soap and hot water.

12.2 Welding

A 4" sanitary ferrule is welded to the bottom of the mash / lauter tun and the boil kettle to aid in removal of spent grains and cleaning.

12.3 Weldless fittings

Holes are made using a step drill bit. All weldless fittings are threaded and mounted with an O-ring and nut.

12.4 Chiller

The chiller is a counter flow design with an inner copper tube of 6m length and an outer tube of PVC.

Copper wire is coiled around and soldered to the inner tube to generate turbulence in the water stream. Soap is used as lubricant to aid in inserting the inner tube into the PVC hose.

The PVC hose is connected to the tee using a hose barb. The inner tube is connected to the tee using compression fittings.

13 — Control system

13.1 Sensors

13.1.1 Flow

A flow sensor with a rating of 0-30 $\frac{L}{min}$ is used to measure the volume of tap water in the HLT.

13.1.2 Temperature

Probes

All probes are K-type thermocouples with a range of 0°C ~400°C.

Interface chip

The thermocouples are interfaced with MAX31855KASA chips.

13.2 Computers and microcontrollers

All sensors are connected to an ATMega328p programmed with the Arduino bootloader and the V-USB library. The ATMega328p then communicates over USB to a Raspberry Pi running Debian Linux. Communication by the user with the Raspberry Pi is performed over a standard ethernet LAN.

Part III

Bibliography and index

Bibliography