Deliverable D - Conceptual Design

GNG 1103
Introduction to Engineering Design

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Wrike Link: https://www.wrike.com/open.htm?id=969517622

1. 0 - Introduction

Beyond the Pale- Brewing Company is a microbrewery residing in Ottawa since 2012. They offer various beers to suit every client. During COVID, the company decided to enter an expansion phase. They require a device to measure specific gravity on their 'in-flow' contraption to alleviate the pressure off their workers. In addition, they'd also like a separate device to measure the specific gravity and temperature of the fermentation liquid during the brewing process.

The following deliverable addresses the design criteria, constraints, functional requirements, non-functional requirements, and technical and user benchmarking of the in-line system.

2.0 - Recap Problem Statement and Design Criteria

Problem Statement: *Beyond the Pale needs an accurate and sanitary method to measure, display and store the specific gravity, in a time-efficient and self-regulating process.*

Table 1.1: Transferring Needs to Design Criteria For the In-Line System

User Needs	Design Criteria
System needs to read specific gravity measurements every 10-30 seconds	Maximum Reading Value (frequency) Timing (min) Automation Control
System needs to display accurate specific gravity values	Accurate Reading of Specific Gravity (% error) Method to Display Results (Plato) Temperature limit (°C)
Device needs to be resistant to yeast build-up and easy cleanup process	Filtration Support (% filtration) Usability under constant conditions Quick set up/takedown process (min)
Device must fit in a 1-½" piping system between two tri clamps	Maximum diameter (Inches) Attachment Capability (clamping)
Device needs to allow for gravity-driven flow	Flowing Method (Gravity)
Material has to be food grade (silicon, stainless steel)	Safety and standards (Food-grade) Public Safety
Device needs to have upfront cost versus monthly subscription costs	Upfront Cost($)

Table 1.2: Target Specifications

	Design Criteria	Ideal Value	Acceptable Values	Units
1	Frequency of SG reading (Time)	Every second (1s)	Every 5-10 (s)	Second (s)
2	Weight of device (mass)	10	At most 30 (so one employee can easily move it)	Pounds (lbs)
3	Filtration efficiency (% filtration)	100	At least 95	Percentage (%)
4	Operating Conditions (temperature)	75-90 (for additional security and reliability measures)	At least >70 (for normal operating conditions)	Degree Celsius (°C)
5	Prototype Cost (upfront)	50-80	At most 100$	Dollars ($)
6	Product Life	10	At least 5	Years
7	Device size (with hole diameter)	10”x4”x4” (inside diameter of 1-½”)	No more than 18”x16”x18” (hole diameter is 1-½”)	Inches (“)
8	Accuracy of Specific Gravity Value from device	100%	At most 1% error	Percentage (%)

3.0 - Conceptual Design subsections

Our in line design can be organized into three critical categories:

1. Measuring the Specific Gravity
2. Display of the results
3. Physical built and connectivity

These subsection are broken down in greater details below:

1. Measuring the Specific Gravity:

This subsystem must be able to measure, read and comprehend the specific gravity value from various sensors. This section has a large emphasis on accuracy and timing. The device must be able to read an accurate result in terms of specific gravity with an error of at most 1%. This will encounter a few difficulties due to the possible yeast build up on the measuring devices which may alter the results. Once measurements are read, an arduino must be able to interpret the results to calculate the final specific gravity value. In addition, the specific gravity must be measured every 5-10 seconds in order to benefit the users of this device.

2. Display the Results:

Once the arduino/code can understand the measurements and calculate the correct specific gravity value, this subsystem must display the specific gravity results. The display must be easily accessible for the user to visualize the results. This section must consider which method/device will display the results and how it will be interconnected to the final product.

3. Physical Built and Connectivity:

This subsystem of the device must consider how the actual device will be built, what materials will be used (food-grade, operating temperature) and how we will physically connect the device to the in-line pipe (fit, size of hole, etc.). This will also consider the estimated product life of the device (corrosion resistant material) and the feasibility of cleaning this device if required. Finally, the weight of the device must also be considered based on its volume and mass in order to determine its transportability.

3.1 - Member Conceptual Designs

Alec Plourde Design:

1. Measurement of Specific Gravity

Concept: This subsystem will calculate the specific gravity results based on readings from various sensors installed into the pipe device. The sensors utilized in this design will consist of one orifice plate, one volumetric flow meter and a differential pressure sensor. In obtaining the volumetric flow (q) of the wort flowing through the system and the differential pressure (ΔP) we can theoretically find the density which would lead us to the specific gravity. The theory is represented below.We can use Bernoulli's law (1) and the continuity law (2) as a basis of fluid dynamics in order to understand the complexity of solving for density (ρ) [1]:

Bernoulli's Equation (1):

$P1 + \frac{1}{2}\rho v1^2 + \rho gh1 * = P2 + \frac{1}{2}\rho v2^2 + \rho gh2$ *, $where\ P = pressure,\ h = height, v = flow\ speed$

** Note: we can eliminate the potential energy terms as there is not difference in height in a straight pipe*

Continuity Equation (2):

$q = v1A1 = v2A2,\ where\ q = flow\ rate\ [m^3/s],\ A = cross\ sectional\ area\ of\ pipe,\ v = flow\ speed$

Combining these equations under ideal conditions while adding a discharge coefficient (Cd for the orifice opening and function of jet size) we can thus create this relation:

$q = C_d * A2 * [\frac{2*\Delta P}{\rho(1-(\frac{A2}{A1})^2)}]^{1/2}$

We can then add an orifice plate in the middle of our system in order to create a temporary change in pressure in the straight pipe which would allow us to find the density of the liquid. The orifice plate has a diameter D2, while the pipe diameter can be expressed as D1. With these 2 diameter values we can combine them into this simple ratio: d = D2/D1. The ***final equation*** then becomes:

$q = C_d * (\frac{\pi}{4})D2^2 * [\frac{2\Delta P}{\rho(1-d^4)}]^{1/2}$, where the variable we are looking for is density (ρ) of the liquid

Once we find the density of the liquid flowing through the system we can use this simple equation to find the Specific Gravity (SG)

$SG = \frac{\rho_{liquid}}{\rho_{reference}},\ where\ \rho_{reference} = water,\ which\ has\ a\ typical\ value\ of\ 997\ kg/m^3$

We would then modify the units in order to get the required units of °Plato as requested by beyond the Pale. The sensors used would find the q value (using the volumetric flow meter) and the differential pressure sensor will find the ΔP value represented in the equation. Knowing these values while the d,D, Cd being constants, we can thus code the arduino uno to solve for the density value which would give us our SG.

Sketches:

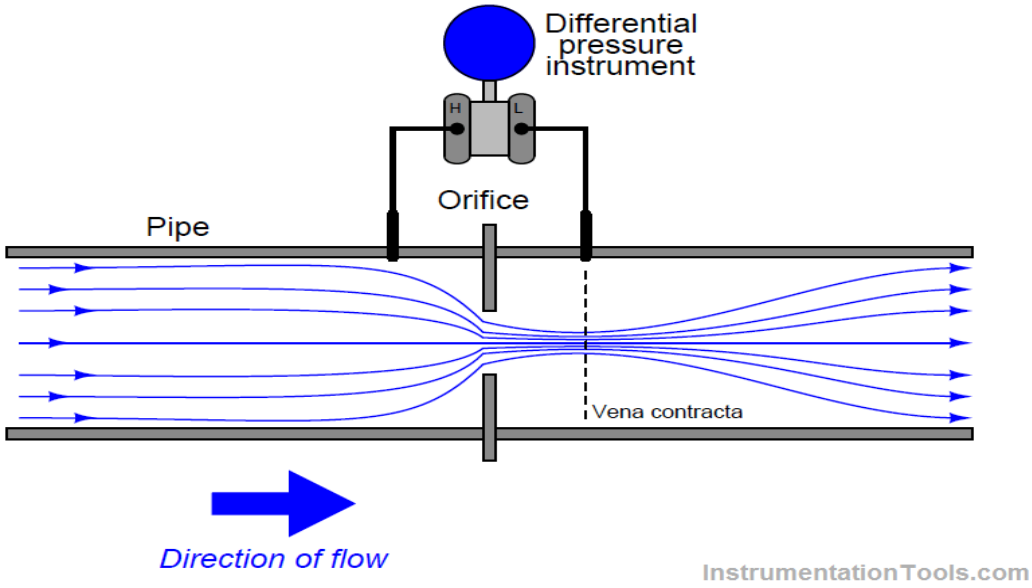


Figure 1.0: Demonstration Sketch showing basic concept of an orifice plate flow meter [2]

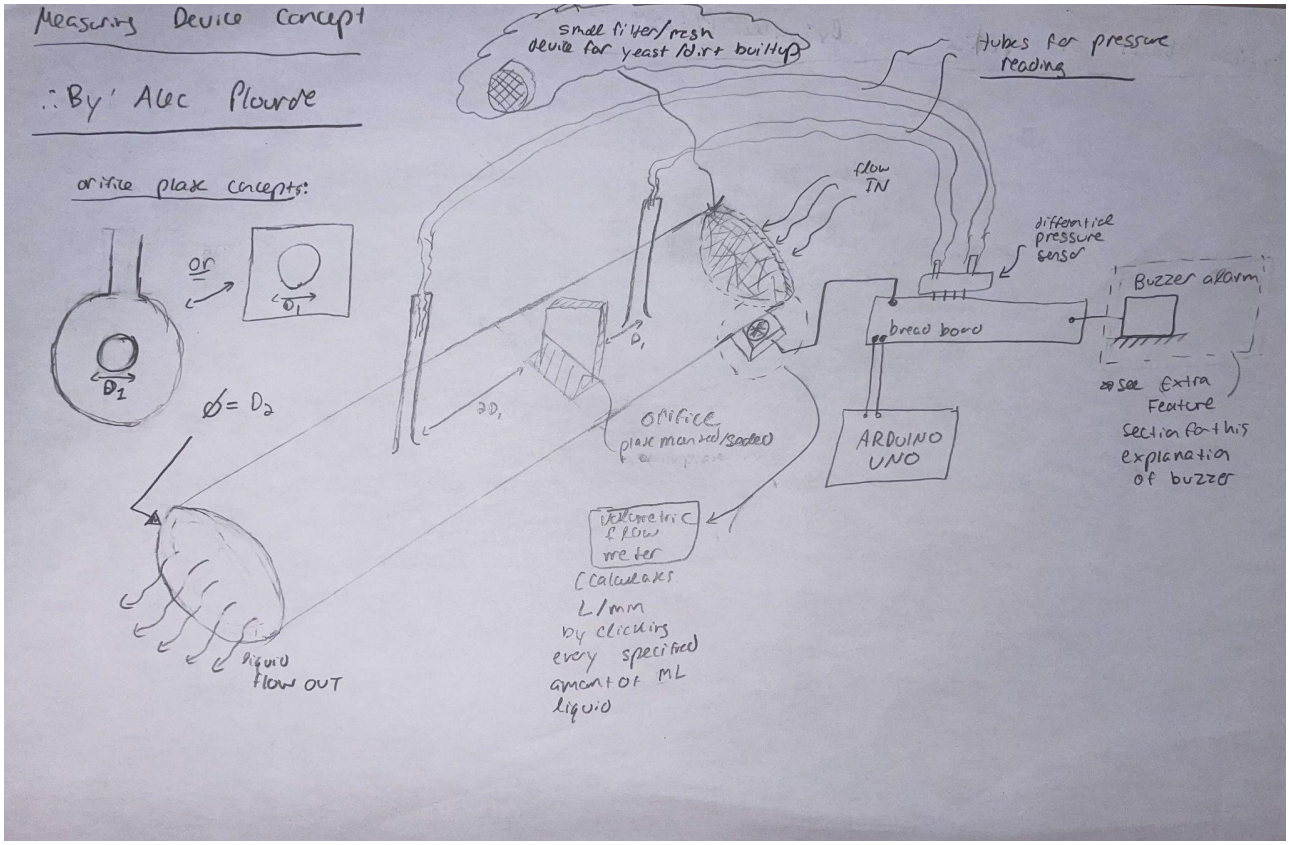


Figure 2.0: Conceptual Design of Measurement Device

Pros:

- This device allows for a functional way of solving the complex problem of getting that specific gravity value without the use of expensive sensors and ineffective methods
- The use of an orifice plate allows for a more cost effective (can make it ourselves or buy a cheap one) when compared to other flow meter options like a venturi or nozzle flow meter
- This system can fit into a more compact style as an orifice plate doesn't take up much volume
- This design allows us to be flexible based on the clients needs (can very the diameter of the orifice plate, the length of our system in order to allow for proper flow recovery, etc)

Cons:

- This requires some concept fluid dynamic and mathematical theory/simplification when coding and solving for the density value
- May require too much energy and power from the arduino uno

Links to potential products For Measurement Device:

- **Differential pressure sensor:** https://www.nxp.com/part/MPX5050DP#/ or https://www.mouser.ca/ProductDetail/NXP-Semiconductors/MPX5050DP?qs=r8OyiFxb6RdEZ0vCbPdH8w%3D%3D (canadian option)
- **Volumetric Flow meter:** https://www.amazon.ca/dp/B08Q7DHQ1S/ref=sspa_dk_detail_2?psc=1&pd_rd_w=CFuc5&content-id=amzn1.sym.c7dca932-da6a-44fc-af09-cc68d2449b34&pf_rd_p=c7dca932-da6a-44fc-af09-cc68d2449b34&pf_rd_r=P7APSZV49HSH0HARRFDC&pd_rd_wg=990fH&pd_rd_r=2307f866-0c53-4e29-9ac7-ded313e7d48c&s=industrial&sp_csd=d2lkZ2V0TmFtZT1zcF9kZXRhaWw or https://bc-robotics.com/checkout/ (for faster shipping times)
- **Orifice Plate:** https://barndoorag.com/teejet-stainless-steel-flow-regulator-orifice-plate-cp4916-54/?gclid=CjwKCAjwkaSaBhA4EiwALBgQaCzDeVoJY4AMGS8zysoFXougGAL5KebEMnhzbinVLXDXGwKMJLizMBoC-ncQAvD_BwE

References for Measurement Device:

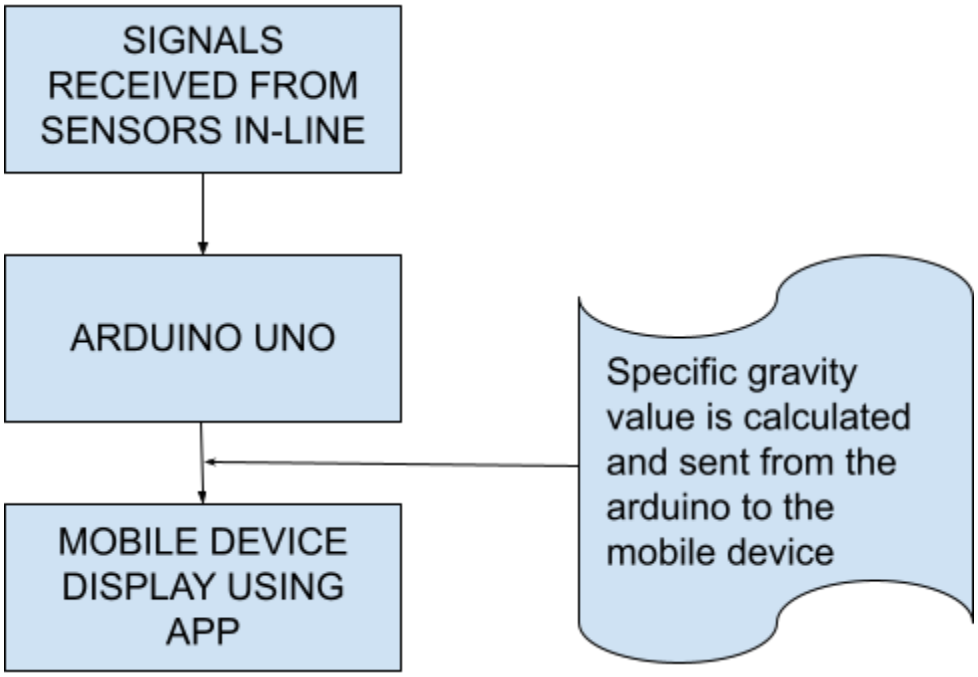
- **For the theory behind the fluid dynamics [1]:** https://www.engineeringtoolbox.com/orifice-nozzle-venturi-d_590.html

- **For the image used [2]:** https://instrumentationtools.com/facts-about-orifice-flow-meters/

2. Display of the Results

Concept: The concept for my design is to be able to read the specific gravity results from a portable device. This would require some type of bluetooth or wifi signal being sent to an external source to which the user must have access to at all times

Sketch:



Pros:

- This would allow for portability, which would enable the users to read the displayed data from anywhere in the building, or from home
- This flexible option can allow for expansion and new features, like implementing a low value alarm, temperature reading, etc. all centrallized in one area.

Cons:

- This requires complex software development to be able to send this data from the measuring device to an external computer or potable device
- This requires beyond the pale to maintain an external device by keeping it on, making sure it is charging, that they have constant access to it etc, which consumes times and energy
- Limitations can occur if bad wifi signal or bluetooth signal occurs when compared to a hardwired device
- The software development/app might require monthly membership cost to maintain and use throughout the year.

3. Physical Built and Connectivity of Device

Concept: The device will be made to fit directly in line with the pipe diameter. The required pipe size has a diameter of 1-½". The material of the device will be alumium. Aluminum is chosen due to its good temperature tolerance, corrosion resistance, light weight and food grade safe standards [1] [2]. The volume and weight of the device can be calculated in future considerations once the required length is known. This can be accomplished assuming the alumimum has a *density of 2.7 g/cm^3* while also utilizing these equations:

Volume of a hollow cylinder:

$V = \pi(R^2 - r^2) * L\,[cm^3],\ where\ L = length\ of\ tube,\ R = Outside\ radius,\ r = inside\ radius$

Mass calculation:

$m = \rho * V\,[g]$

Using these equations we would ensure our device is under the target weight requirement of at most 30lbs by doing a simple conversion from g to lbs (1lb = 1g/453.6).

Sketch:

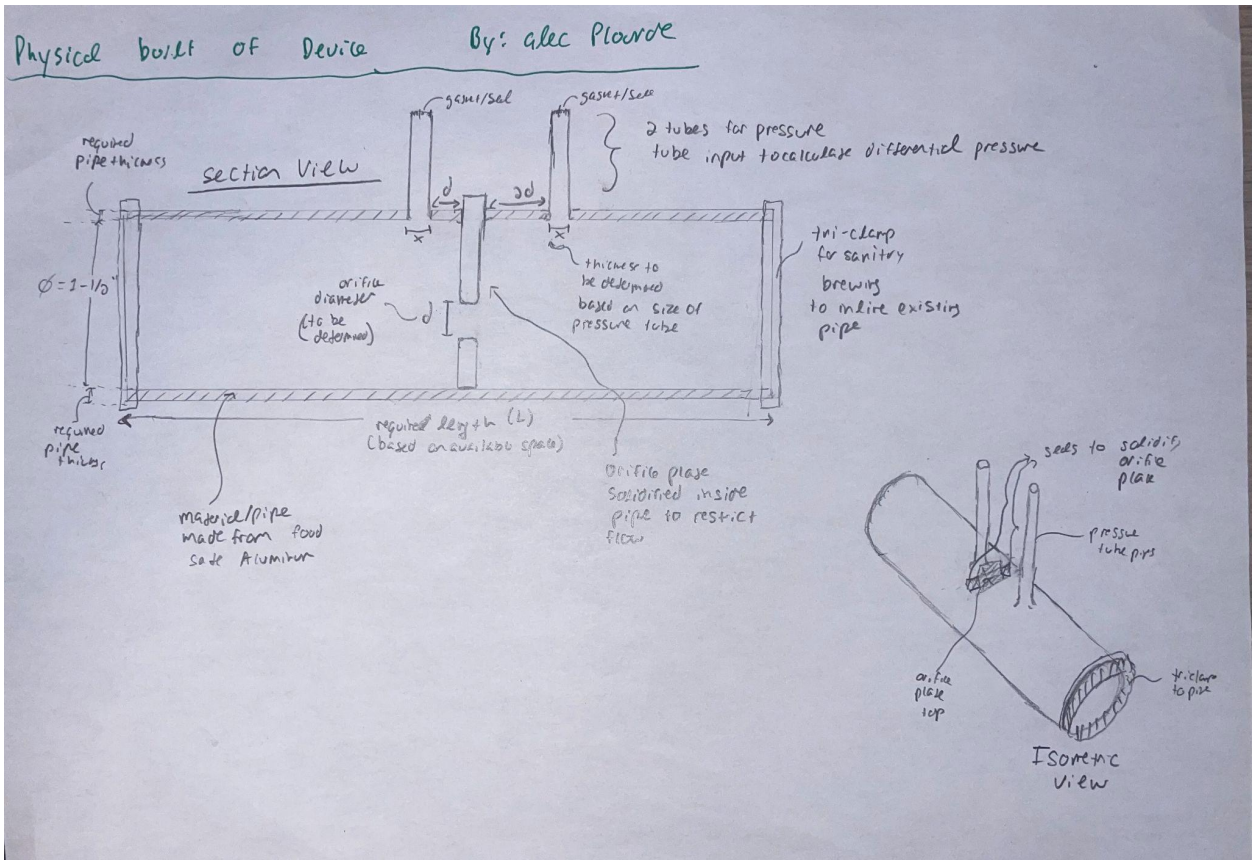


Figure 3.0: Concept for physical look and connectivity of device

References for the Physial built of the design:
[1]https://www.alumeco.com/knowledge-technique/certificates-and-documents/aluminium-in-the-food-industry/
[2]https://www.rsc.org/periodic-table/element/13/aluminium#:~:text=It%20has%20low%20density%2C%20is,and%20the%20sixth%20most%20ductile.

4. Extra Feature

Concept: The in-line process is a very time sensitive process in regards to the quality of the wart and its usability. In order to assist the users in quickly determining when the specific gravity is below its critical threshold, a buzzer will be implement into the system (connected to the arduino) to which it will go off until the value is above the critical point.

- Arduino Buzzer:
https://www.amazon.ca/Buzzer-Electronic-Continuous-Sounder-Length/dp/B07DSC38VK/ref=asc_df_B07DSC38VK/?tag=googleshopc0c-20&linkCode=df0&hvadid=292918847889&hvpos=&hvnetw=g&hvrand=2671231857000659228&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=1002232&hvtargid=pla-718645754392&psc=1

Gabrielle Graceffa Design:

1. Measurement of Specific Gravity

Concept: This device calculates the specific gravity results through the readings of one sensor and programming installed into the pipe. The sensor computes the density of the liquid in the static component of the device.

$$SG = \frac{\rho Object}{\rho Water}$$

Since the in-line system is held at a constant temperature, the density of the water will relatively be constant (997 kg/m³) in a static environment.

A density sensor for liquids will measure the density of the inline pipe.

Pro:
- Affordable

Cons:
- If any part of the controlled variables shift/change, the device will not work

2. Display of the Results

Concept:
The device has a LED screen that will blink green and show the computed specific gravity every 10 seconds if the specific gravity is between the accepted specific gravity for beer and blink red when it is not.

Figure 1.0 Display of results

Pro:

- Easy to see
- Easy to read
- Water proof if there is some beer spilling anywhere

Cons:

- Can get annoying to see
- Does not work for the people who have color blindness

3. Physical Built and Connectivity of Device

Concept: The design is in a stainless steel tube connecting to the in-line system through clamps. The door one (left side) will open and close for 10 seconds while door 2 (right side) opens every 10.5 seconds and closes every 9.5 seconds. There is a smaller tube that connects to the DS18B20 sensor that takes a sample of the beer and sends the results to the connected arduino uno. Through the programming of the arduino there will be an if else statement. The if else statement entails that when theρObject is between a certain range then the arduino that is also connected to the LED screen display to blink green and vice versa.

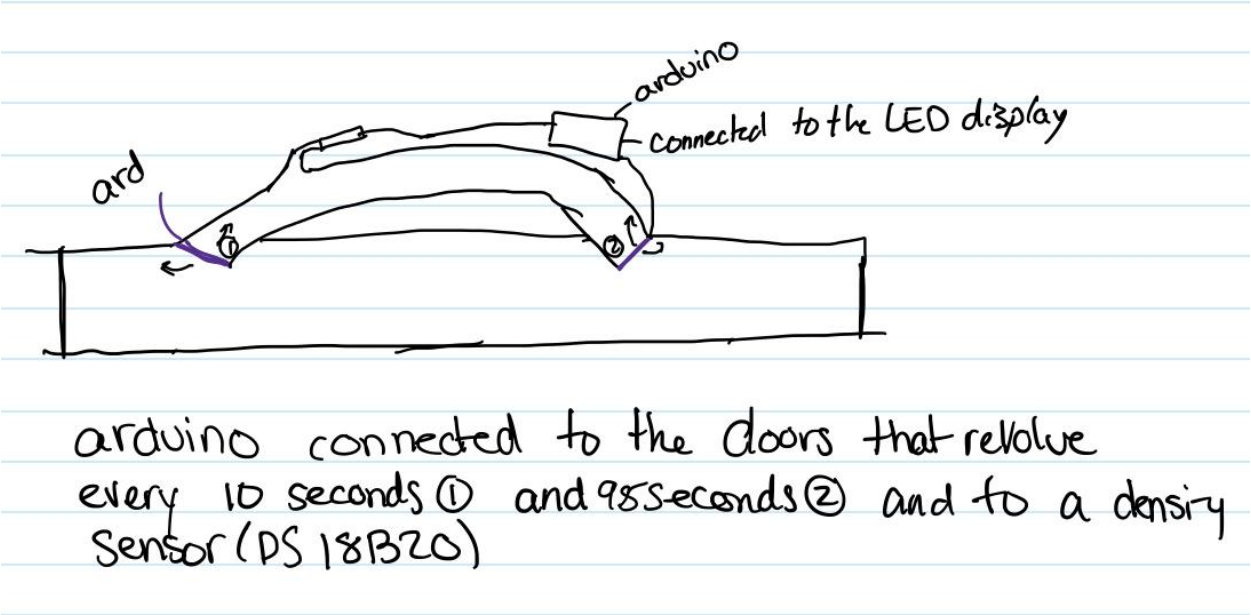


Figure 2.0 the physical concept

Pro:

- Easy to clean
- Easy to understand the readings
- Easy to remove from the in-line system
- Affordable

Cons:

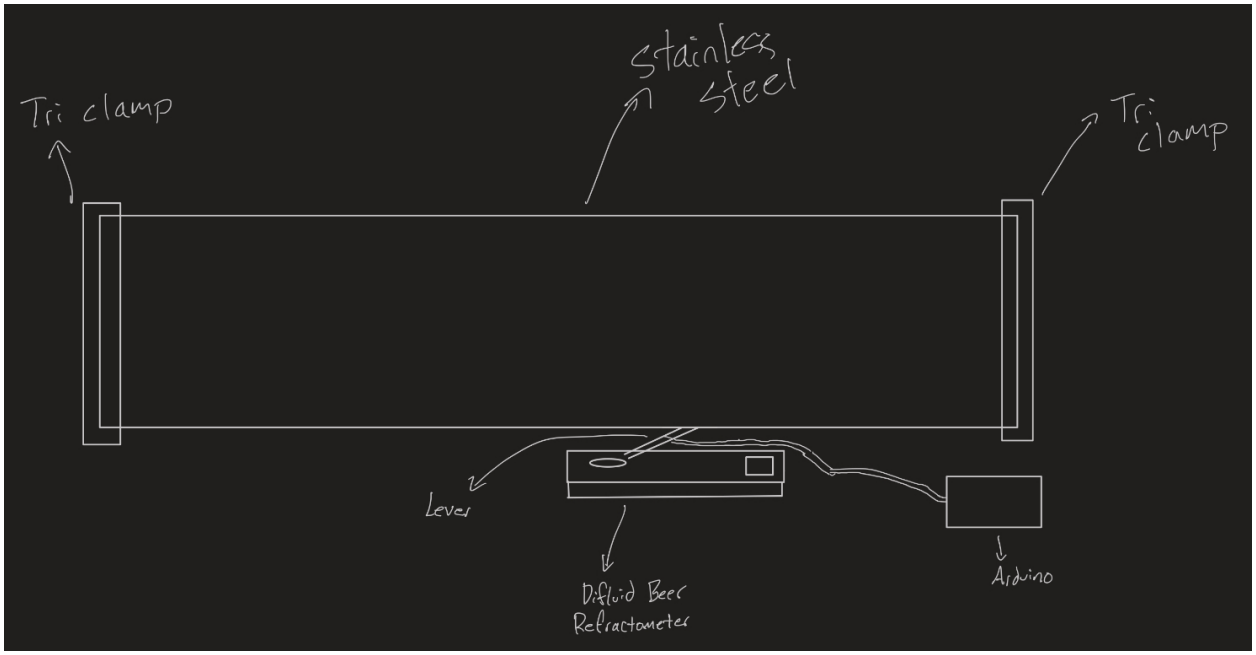
- The device degrades overtime providing an inaccurate reading
- Research is relatively new so it is unsure if this sensor can be programmed to work this way

References:

Stainless steel: https://www.morebeer.com/articles/stainlesssteel101

Arduino density DS18B20:
https://www.researchgate.net/publication/338330461_The_Design_of_Digital_Liquid_Density_Meter_Based_on_Arduino

Thomas Johnson Band Design:



1. Measurement of Specific Gravity

For measuring specific gravity I choose to use the Difluid beer refractometer. This refractometer will be given a sample of beer from the pipe every ten minutes, this is controlled by a lever that is opened every ten minutes which is controlled by an arduino.

Pros

- Simple design and easy to clean.
- Can measure the specific gravity of beer at ± 0.1 percent accuracy.
- Unaffected by external lighting.
- Takes one hour to charge and will last thirty days on one charge.
- Automatically sends the data taken from the sample to an app that can be downloaded on your phone.
- It only needs one drop of the sample to measure the specific gravity within 2 seconds.

Cons

- The difluid beer refractometer is over our price range of one hundred dollars.
- Still needs a sample that needs to be removed from the vats. But this sample is very small.
- The lever system could degrade over time leading to miscalculated readings.

2. Display of the Results

For displaying the results, instead of creating our own website for storing and showing data. We use the app already linked to the refractometer which can be used on your phone and will store the data for you.

Pros

- Easy to use.
- Already stores the data.
- Is available on your phone.
- Connects to the refractometer through bluetooth

Cons

- Sometimes the link between the refractometer and the app can disconnect which will need the user to manually reconnect them.
- The difluid beer refractometer is over our price range of one hundred dollars.

3. Physical Built and Connectivity of Device

We will use stainless steel as that is the most common material used in breweries for the vats and pipes. It is high temperature resistant, corrosion resistant, has hygienic properties and food grade safe standards. To connect this pipe to the pipe in the factory we will use a tri clover clamp that this brewery already uses in their factory.

Pros

- The workers in the factory already know how to use the tri clover clamps.
- Stainless steel is the most common and best material to use in breweries.
- Simple and easy to take off and clean.

Cons

- It is possible for chloride cracking in stainless steel.
- Can maybe degrade over a long period of time in a high temperature environment.

References for physical design

1. https://wldstainless.com/the-choice-of-stainless-steel-material-for-brewery/

1. Difluid Beer Refractometer:
- https://www.amazon.ca/Refractometer-Companion-Fermentation-Precision-Resolution/dp/B0B9GWM9FJ/ref=sr_1_4?crid=188L4S38C32BX&keywords=specific+gravity+sensor+beer&qid=1665082869&qu=eyJxc2MiOiIxLjMwIiwicXNhIjoiMC4wMCIsInFzcCI6IjAuMDAifQ%3D%3D&sprefix=specific+gravity+sensor+beer%2Caps%2C64&sr=8-4
2. Tri clover clamp:
- https://www.dernord.com/products/2inch-tri-clamp-union-set-tri-clover-clamp-2-pcs-sanitary-pipe-weld-ferrule-silicone-gasket?variant=27294391992384&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&gclid=CjwKCAjwtKmaBhBMEiwAyINuwKK_bbP1uLx-Tt1EeQ-EHNxUHqsseUV31qOgafNXX3-1Flgngwpv-BoCHzEQAvD_BwE

Emmett van den Broek Design:

1. Measurement of Specific Gravity

For the measurement of specific gravity I chose to use the Beer Wort Refractometer. The refractometer will be given a sample (2-3 drops) whenever the user needs one by using a small slider that is able to drop a very small amount of beer that can be used as a sample.

Pros

- Easy to use
- Cheap and well within our price range
- Measures specific gravity
- Easy to clean

Cons

- Needs a sample that comes out of the brewing process
- Potential for user error as you have to look into the device to see specific gravity

2. Display of the Results

The display of the results using this device is not the greatest system. The user must actually look into the Beer Wort Refractometer to view what the reading of specific gravity is. The user can then possibly put the viewed result into a computer/device that can store this data. This could then easily be sent to an LCD screen.

Pros

- A lot easier than their current method
- Storing the data is fairly simple
- User only has to rely on themselves for the measurement
- In our price range

Cons

- Not fully automated
- User has to type data into a computer or device that can then be displayed on a screen

3. Physical Built and Connectivity of Device

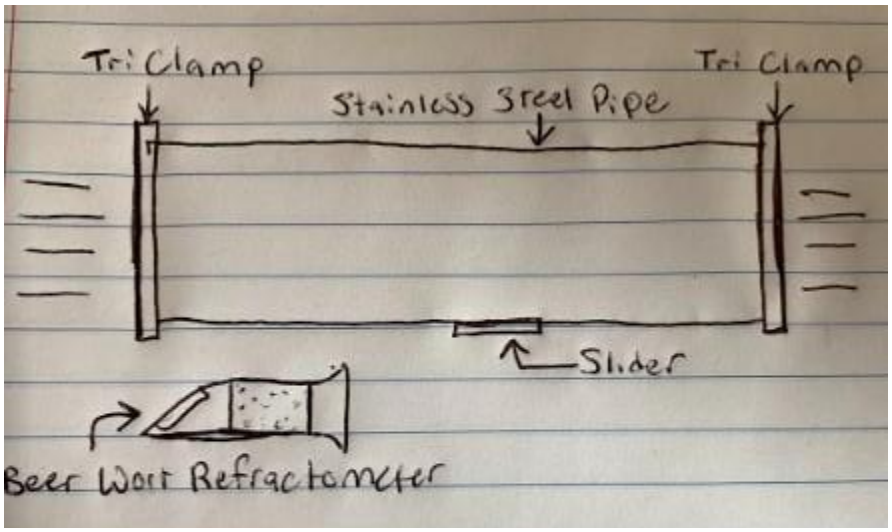
This design concept will be made of stainless steel as this is what a majority of the pieces in the brewing process are made of. Stainless steel is corrosion resistant, can handle high temperatures, is food grade and sanitary. The actual device does not have to be connected to the pipe as the user just has to put a few drops of beer into it and look through the scope. The pipe will be connected using tri clover clamps.

Pros

- Stainless steel is food grade, corrosion resistant and can handle high temperatures
- Beyond the Pale is familiar with the tri clamps already
- Easy to remove and clean

Cons

- Stainless steel could wear down after a long period of time under high temperatures



References

Tri Clover Clamp
https://www.dernord.com/products/2inch-tri-clamp-union-set-tri-clover-clamp-2-pcs-sanitary-pipe-weld-ferrule-silicone-gasket?variant=27294391992384&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&gclid=CjwKCAjwtKmaBhBMEiwAyINuwKK_bbP1uLx-Tt1EeQ-EHNxUHqsseUV31qOgafNXX3-1Flgngwpv-BoCHzEQAvD_BwE

Beer Wort Refractometer
https://www.amazon.ca/Refractometer-V-Resourcing-Specific-Gravity-1-000-1-130/dp/B06XSYH9L8/ref=asc_df_B06XSYH9L8/?tag=googleshopc0c-20&linkCode=df0&hvadid=459470607295&hvpos=&hvnetw=g&hvrand=7941815698460574966&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000668&hvtargid=pla-420135946715&psc=1

Ashley Garofalo Design:

1. Measurement of Specific Gravity

Concept: This design measures the specific gravity using the density of the fluid (beer) and water. It is assumed that the temperature and density of water remains relatively consistent throughout the process (997 kg/m³), and therefore, does not need to be re-evaluated.

SG = pFLUID/pH2O

Where SG represents specific gravity, pFLUID represents the density of the fluid being tested (beer), and pH2O represents the density of water.

Pros:
- Easy to evaluate
- Within price range

Cons:
- If variables change (ex. change in water density), readings will not be accurate

2. Display of the Results

For this device, measurements of the specific gravity will be sent to an individual screen on each tank. This way staff can easily check and record numbers/values.

If the specific gravity is exceeding or well under the range for beer, the screen displaying the information will flash red.
If the specific gravity is within an acceptable range for beer, the screen displaying the information will remain normal.

Pros:
- Easy to read/record
- Signals staff members when beer is not in a good range
- Updates every 5-10 seconds

Cons:
- The flashing screen can be irritant to those with seizures
- The flashing screen is not efficient for those with visual impairments
- Staff members still have to go around and record the information

3. Physical Built and Connectivity of Device

This device uses aluminum as it has a high temperature tolerance, is lightweight, corrosion resistant, and low cost. Aluminum is also food grade standard, which is a must when working with beer. The vertical probe has a hole at the bottom to allow for flow into the probe. A sample is taken from that probe and the specific gravity is measured, which is then sent to an LCD screen and displayed. A door (on the side of the probe) opens every five seconds to allow the old sample to continue to the outflow, and a new sample to measure specific gravity.

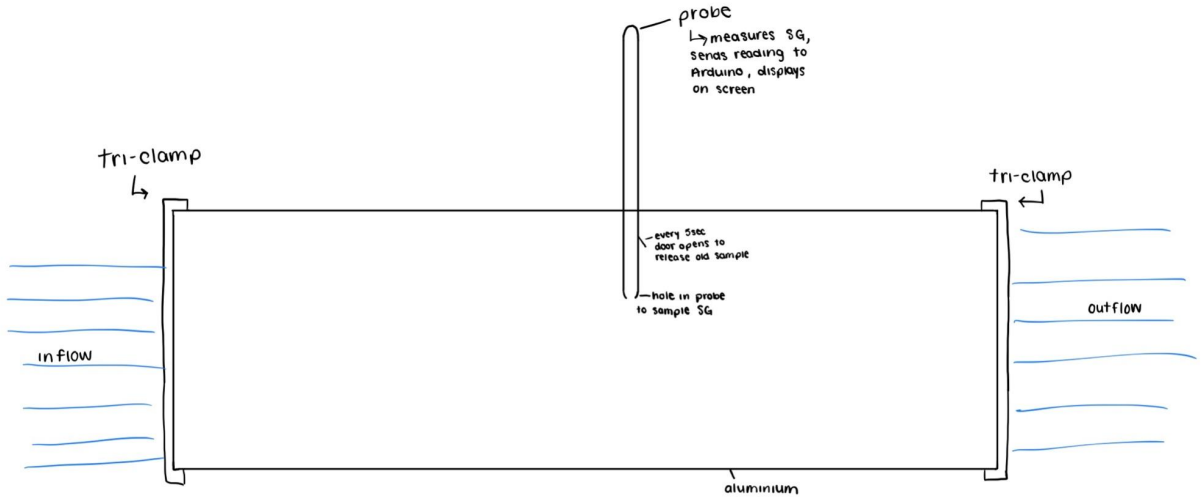


Figure 1 - Physical Built

Pros:

- Brewing company already uses tri-clamps
- Aluminum is food grade safe
- SG is sent to a screen on the tank
- Probe is easy to remove for cleaning purposes

Cons:

- Aluminum cannot take too much force without breaking (low tensile strength and impact tolerance)

References/Citation:

Aluminum Information
https://www.marlinwire.com/blog/food-safe-metals-for-sheet-metal-wire-forms
Specific Gravity
https://study.com/academy/lesson/what-is-specific-gravity-definition-formula-calculation-examples.html

4.0 - Final Design Concept

Our design selection for each subsystem can be broken down below:

1. **Measuring the Specific Gravity =** Alec Plourde's Idea: Orifice plate
2. **Display of the results =** Gabrielle Graceffa's idea: LED Screen display the visible specific gravity number
3. **Physical built and connectivity =** Alec Plourde's idea: physical built for plate and pressure tubes
4. **Extra Features included =** buzzer for alarm (to indicate when the specific gravity is in a bad range

This final system can be compared with our design criterias and target specifications as seen in deliverable C:

Design Criterias	Measuring Specific Gravity Concept	Display Results Concept	Physical Built and Connectivity Concept
-Maximum Reading Value (frequency) -Timing (min) -Automation Control	Yes - every 5-10 seconds and will be fully automated with the arduino	N/A	N/A
-Accurate Reading of Specific Gravity (% error) -Method to Display Results (Plato) -Temperature limit (℃)	Yes - design should have limit of 1% error during calculation	Yes - the LCD screen will be mounted to the device and will display the results of the specific gravity value	Yes - The device and built will be able to sustain the operating temperatures of 60-70
-Filtration Support (% filtration) -Usability under constant conditions -Quick set up/takedown process (min)	Yes - The device will have an adequate in-line filter at the start	N/A	Yes - the device will be able to be taken down quickly with the triclamps and be bale to be set up efficiently
-Maximum diameter (Inches) -Attachment -Capability (clamping)	N/A	N/A	Yes - The device will have the required diameter of 1-½" along with its clamping abilities.

4.1 - Finalized Concept

Our final design concept uses Alec Plourde's idea for measuring specific gravity, Gabriella Graceffa's idea for displaying our results and Alec Plourde's idea for the physical build and connectivity. The idea for measuring specific gravity uses various sensors installed into the pipe, who's readings can be used to calculate the specific gravity. The idea for the display of our results will take the measurement of specific gravity and display it on an LED screen every 5-10 seconds. There will also be a buzzer that goes off if the specific gravity has dropped below the critical value. The idea for the physical build and connectivity will be physically built for the plate and pressure tubes in Alec's design and will fit directly in line with the pipe. The pipe will be made of aluminum due to its advantageous thermal and mechanical properties.

Pros

- Accurate specific gravity measurement
- Fully automatic (besides cleaning)
- Easily and clearly displays specific gravity
- Buzzer will notify if the specific gravity is not in the desired range

Cons

- Aluminum is not the strongest material and cannot take too much force
- Aluminum may be a little less cost efficient