Linköping University | Faculty of science and engineering
Bachelor thesis, 15 hp | Product Development
Spring term 2024 | LIU-IEI-TEK-G–24/02386–SE

Wine Monitoring

Design of the sensor containing product
TEIO47
TMKT82

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A project presented for the degree of
Bachelor of Product Development

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Reading Guide

The structure of this thesis has been adjusted to accommodate partial results and discoveries that are uncovered along the way. This thesis will therefore deviate from the standard template in order to ease the reading. Diversions from the standard template most notably include the restructuring of the theory, results and discussion chapters into one analysis phase. Within the analysis phase, each topic is treated somewhat as a separate miniature report, containing everything the reader needs to know about the process, from information gathering to conclusions and evaluation.

Furthermore, in some cases the thesis may not present its results in perfect chronological order. This is done in order not to confuse the reader by jumping back and forth between independent topics.

For full disclosure, it should be noted that the language model ChatGPT-3 by OpenAI was used to proofread this report for grammatical errors, spelling mistakes, and poor wording. The model only identified errors, and all changes were made manually.

Abstract

Continuous monitoring of the wine fermentation process is critical for ensuring quality and consistency in winemaking. This report details the design and material considerations for a sensor containing product intended for integration into existing wine fermentation equipment. Key requirements include chemical resistance, thermal stability, mechanical robustness, and food safety compliance. Materials were evaluated based on their resistance to acidic and basic environments, alcohol, and various other organic compounds found in wine. Additive manufacturing techniques were explored for their potential to produce components, with a focus on ensuring materials meet food safety standards. The report concludes that while additive manufacturing is promising for non-contact parts, it is less suitable for components in direct contact with wine due to challenges in ensuring food safety and thermal stability. Future work will focus on enhancing material sustainability, developing waterproofing solutions for FDM-printed parts, and optimising the product design for durability and ease of integration. In the meantime more proven materials such as stainless steel, glass and various high performance polymers should be the subject of further investigation.

Acknowledgements

We would like to express our sincerest gratitude to our supervisor, Renee Wever, for his help and guidance throughout this thesis work. We are also thankful to Marie Bengtsson, Juan Ruiz, and Emma Walters for their support.

We would also like to thank the staff at Padova University: Donatella Banzato, Lorenzo Cocola, Luca Poletto, and Elena Barbera, for taking good care of us and providing us with information vital to make important decisions.

Furthermore, we would like to thank all the people who let us visit their vineyards, showed us around their work environment and participated in interviews. Without them, this project would not have had much to stand on. Our sincerest thanks to Karin Birch, Niclas Albinsson, Jesper Appelin, Emma and Romain Berto, Rickard Sjöberg, Giorgio and Rosanna Salvan, and Marco Zanovello.

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1 Introduction

The introduction chapter describes the background to the project, a motivation for its importance and its primary goals.

1.1 Background

This bachelor thesis is part of a larger cross-institutional project that is in turn part of the EU research project ATTRACT. ATTRACT has funded, among other projects, the development of two separate technologies for advanced measurements.

The first technology was developed at the University of Twente, in the Netherlands, and is currently in the possession of the company Unicorn DX. The technology can make quantitative measurements of particles in the range of 10 to 100 nanometers. The primary use for the technology lies within the medical industry, detecting pathogens and biomarkers such as viruses and proteins. However, getting approved for medical use on humans is a lengthy process and therefore, the company runs the risk of facing bankruptcy before it is able to put a product on the market.

The second technology was developed at the University of Padova, Italy, and is currently in the possession of the company PiPe4.0. Using Raman spectroscopy, the technology can make precise measurements of gas compositions without direct contact with the gas. The intended use for the technology is within biogas production and transportation of gas through pipelines. The system that the technology is used in is split into two separate units, one larger and more capable unit, and a smaller simplified unit.

Previous studies concluded that a potential alternative use case for both these technologies could be found within the wine and beer making industries. Finding a suitable application for the technologies could provide a second source of income, enabling the survival of the two companies until each technology can be introduced to the market in the role they were intended for.

Since neither technology was created with the intent to be used in this manner, they are likely unfit for implementation in the winemaking process in their current form. Research is therefore needed on what characteristics are of importance when designing a sensor containing product that is to, in some way, interact with wine. It is also of interest what possible solutions are suitable to this particular application.

1.2 Purpose

The purpose of this thesis is to explore and determine the requirements for the product to be successfully implemented in wine production. The thesis will concentrate on researching important mechanical properties in the physical product. In particular details that interact with the wine, the tank and the immediate environment, will be in focus.

The main problem statements that will be researched are:

- What are the requirements and limitations for the product to be successfully incorporated into existing winemaking equipment?
- What mechanical principles could be utilised to achieve these requirements, and how does this affect the choice of materials?

To answer these questions, there is a need to explore the details of the product's potential interactions in the wine's production process and with the product's immediate environment. The immediate environment refers to the climate of the product's surroundings, other preexisting technologies and products, on-site routines as well as the many other factors that may come into play that make winemaking such a complex process.

1.3 Aim

The overarching goal of this thesis is to present design principles and requirements to create a basis for future products to be constructed upon. This thesis's results should together with results from the parallel theses ”Designing a User Interface intended for Winemaking” and ”Business value for developing a wine monitoring product” form an adequate basis for further development of a wine monitoring system containing at least one of the assigned technologies.

1.4 Scope

Due to the lower technical complexity and ability to make meaningful corrections midst fermentation, beer brewing is disregarded in favour of wine production. Beer producers are, however, kept in mind as a secondary user group. If only minor changes are needed to adapt a concept originally intended for wine production to the beer brewing process these will be considered.

Although the product might be applicable to markets worldwide, this thesis will be limited to the EU. This is due to the mounting challenge of identifying and complying with food safety standards in multiple regions. Another potential issue could be different standards for products already in use.

In cases where the specific equipment already in use may influence the adaptations this thesis aims to result in, equipment typically in use by medium-sized vineyards will be used as reference. The definition used for medium-sized vineyards is a total cultivated area between 1 and 10 hectares [Nikolina Šajn, 2023]. With an average density of 5 000 vines per hectare and a yield from 1,125 to 1,5 litres per vine, this equates to an annual yield of 5 625 to 75 000 litres of wine per vineyard within our target group [Norbert Tischelmayer, 2023].

2 Methodology

To determine whether the product is well suited for its environment and purpose, in-depth knowledge regarding both material properties and production methods is essential. Part of the research also regards the applications of the product, which might in turn both be influenced by and influence the design of the final product.

2.1 Literary Review

To build an understanding of the field of the thesis, it is necessary to review previous work and research available. Thus working through material and processing studies on related topics, a better understanding of the task at hand can be gained. The literary material varies greatly and includes amongst other sources: technical studies of materials, material property charts, research papers on the chemical composition of wine, product catalogues, production methods of appropriate materials and specialised industry reports from interest groups.

The process to determine relevant materials consists of mostly theoretical research. Extensive research is conducted on what materials are suitable for an industrial environment and understanding what abrasion these may be exposed to. In addition to this, production methods are explored to account for production complexity and exploring the suitability of certain methods that allow for unique materials.

2.2 Standards and Regulations

Working with the food industry, it is of upmost importance to abide by food standards and regulations. Thus, regulatory frameworks will be taken into great consideration and researched extensively since this category plays a critical part in deciding a materials viability. It may also reveal new requirements specific to materials, such as surface finishes that need to be kept sufficiently clean to abide by health codes. This, in turn, dictates what methods that are available and therefore also sets limitations to what can be constructed.

2.3 Deliberation with Experts

To aid with parts of the project, consultation with individuals with certain expertise is conducted. For example, when exploring manufacturing and production methods for a product that will be created in a limited amount, it is appropriate to consult an expert in additive manufacturing techniques to verify whether its sustainability and whether other manufacturing techniques should be considered. Using this expertise to gain insight into what the next step could be and favourably, forwarding us down the line of niche competences,

2.4 Field studies

A number of field studies are performed. Visits are made to vineyards and wineries in Sweden and Italy as well as the University of Padova. Interviews are held with various persons of interest, which are summed up in separate interview documents, see Appendix B and C. The interviews are held in a semi-structured manner and answers are recorded by taking notes. Memorable quotes are written down and some brief recordings are taken. All interviewees have signed a consent form, allowing their answers and photographs to be published in this report.

During the field studies, the feasibility of the product will be evaluated, allowing for an in-depth on-site understanding of how a future product may be used. In particular, the already present attachment points are of interest. This should grant a new perspective and give important insights to where and how the product could be used, and ultimately result in what steps need to be taken to achieve a working product.

3 Analysis Phase

In order to guarantee that the materials and mechanical principles recommended by this thesis do not in any way risk harming the wine when in use, research should be conducted on the appropriate areas of food safety standards. Potential causes of damage to the wine could be chemical or biological contamination, either through the accidental introduction of unwanted microbes or materials that are prone to air leakage and corrosion. By simply adhering to relevant food safety standards it is believed that most of these issues can be averted, and they should therefore be studied and condensed in the this chapter.

Another downside to corrosion, apart from the potential contamination of the wine, might be a decreased product lifetime. Aspects that affect corrosion tendency in materials are therefore interesting areas of research.

To further our understanding of wine's effects on materials and its properties, it is of interest to research the contents of wine and its chemical composition. This, which in turn may assist in developing an understanding of what precautions and actions that can and need to be taken to ensure a product that will not contaminate the wine. As the research needed for this thesis overlaps somewhat with that conducted in the greater project, this chapter borrows some content from the main project report.

At the end of each section in this chapter is a short description of the resulting requirements. These are later group together and summarised in Table 5, hence the numbering in this chapter might appear out of order.

3.1 Requirements of the Requirements

To establish the usefulness of the requirements from the results of this thesis, these requirements must be well defined and follow some requirements of their own. The following criteria should be applied to all requirements:

- The requirement must be defined in a way that it can be verified as completely fulfilled or not.
- The requirement must be worded in such a way as to not confine/restrict itself to a set solution unless it is deemed vital or evidently superior.

After each section in the analysis phase, the concluded requirements from the corresponding chapter are presented, which in turn are compiled in table 5.

3.2 Concept

The concept in question is "Pump on the Tank" [Gunnar Berg et al, 2024] from the main research paper [Gunnar Berg et al, 2024]. Figure 1 shows an early illustration from the concept generation stage.

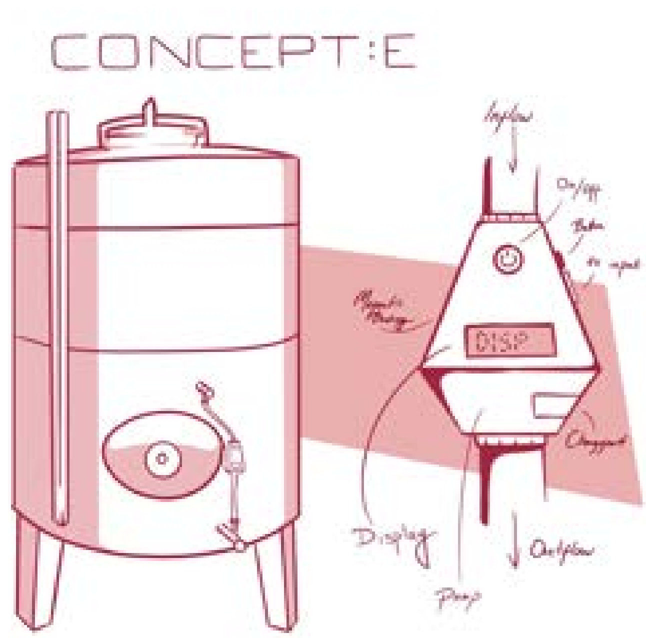

Figure 1: Concept: Pump on the Tank

The discoveries uncovered in this thesis are regarding the mentioned concept and are intended to be applicable in the development and manufacturing of the previously mentioned concept.

3.2.1 Brief Concept Description

The concept "Pump on the Tank" utilises an attachable extension which connects to the fermentation tank racking outlet. Once connected, the product should be able to extract samples from the tank into itself, where it is subsequently tested for various data. This method would offer the winemaker continuous monitoring of the wine and various indicators of the fermentation progress, without the need for a constant presence in the winery, relieving part of the wine makers workload. Examples of such indicators are biomarkers such as bacteria, proteins and yeast, as well as chemical properties such as pH and alcohol content

[Gunnar Berg et al, 2024]. A rendered result of the sensor containing product is provided in appendix D.

3.2.2 Implications on project

The most obvious implication of the concept choice on the mechanical properties of the product is the need for compatibility with racking outlets on commonly used wine tanks. The product should be compatible with as large a number as possible of already in-use equipment with the target group. Attaching the product to the racking outlet also implies direct contact with wine at higher pressure than normal, for which the dimensioning requirements need to account.

Furthermore, the product should be able to operate independently of any input for up to a month at a time [Appendix B]. This implies that the electronics would be battery powered, and in order to limit the size of the product as a whole this battery would likely need to be as small as possible. With reduced size, the battery capacity would likely be a limiting factor and energy efficiency is hence an interesting property. Whereas sensors and other miscellaneous electronic equipment often can be modified to draw minimum power, motors tend to be more prominent power consumers. In order to extract wine from the tank and then dispose of it back into the tank in a controlled manner the product will need some sort of pump. Energy efficient pumps should therefore be preferred.

Lastly, wine processing needs to adhere to relevant food and beverage safety regulations. This means that all products in contact with the wine need to be cleaned and kept to a high sanitary standard. This goes for the sensor containing product as well and choices of materials, production methods and mechanical principles should be made with sanitary concerns in mind.

3.3 Standards and Regulations

Standards and regulations that govern production requirements and material requirements.

3.3.1 EHEDG Guidelines

EHEDG guidelines are standards developed by the European Hygienic Engineering and Design Group for promoting hygiene in food processing and packaging. These guidelines cover various aspects of equipment and facility design to prevent contamination and ensure food safety. They include recommendations for materials, surface finishes, construction, cleaning, and maintenance to achieve hygienic design principles. EHEDG guidelines are widely recognised and used in the food industry to ensure compliance with hygiene standards and regulations [Jürgen Hofmann et al, 2018].

3.3.2 EC 1935/2004

EC 1935/2004 is a European regulation concerning materials and articles intended to come into contact with food. It establishes general safety requirements and standards for such materials and articles to ensure that they do not transfer harmful substances to food in quantities that could endanger human health, change the composition of the food, or deteriorate its properties. The regulation applies to all stages of production, processing, and distribution of materials and articles intended for food contact within the European Union. Compliance with EC 1935/2004 is mandatory for manufacturers, importers, and distributors of food contact materials and articles within the EU [Ekaterina Karamfilova, 2016]. Figure 2 shows the logo the regulation, which can be found on many food processing products.

Figure 2: EC 1935/2004 certificate mark

3.3.3 ISO 4439:1979

A popular type of tubing used for winemaking is polyvinyl chloride (PVC) tubing. These tubes must adhere to ISO 4439:1979 which regulates unplasticised polyvinyl chloride pipes and fittings, to ensure they are food grade [International Organization for Standardization, 2020].

3.3.4 EN ISO 4892-2:2013

The materials used in the product must be resistant to UV-induced degradation, including changes in colour, brittleness, or loss of mechanical properties. Furthermore, materials should not undergo chemical reactions that could compromise their integrity or release harmful substances when exposed to UV light.

There are a multitude of standards, depending on material, that ensure a material's resistance to UV. One of these is EN ISO 4892-2:2013 [International Organization for Standardization, 2013], which ensures that plastic maintains its structural integrity under UV cleaning protocols.

3.3.5 Implications of the Standards and Regulations

It is important to note that though all standards and regulations are critical for the development of the product, all standards are not relevant or applicable to all product results due to some parts not being material dependent. The interchangeability of materials for parts allows for variation in components whereby potentially excluding some materials and in turn removing the need for a specific standard or regulation.

3.3.6 Resulting Requirements

The standards and regulations chapter results in four requirements:

- 2.1 Comply according to EHEDG guidelines
- 2.2 Comply according to EC 1935/2004
- 2.3 Comply according to ISO 4439:1979
- 2.4 Comply according to EN ISO 4892- 2:2013

3.4 Mechanical Principles of Attachment

The mechanical principles that allow for components to attach and interact with others, to ensure a secure fit and a correct seal with minimal wear to the materials.

3.4.1 Fittings

The standard of threads and fittings on wine tanks vary depending on location of manufacturing. In the EU, the most common are Tri-clamp and DIN fittings.

Tri-clamp fittings are commonly used in the wine industry due to their sanitary design, which is essential for maintaining the quality and purity of the wine. The standard for Tri-clamp fittings is governed by ASME BPE (Bioprocessing Equipment) standards, particularly for stainless steel tanks [ASME, 2023].

Deutsches Institut Fur Normung (DIN) Fittings. Particularly common in European countries, this standard uses metric threads. DIN standards related to sanitary design and hygiene may be relevant for equipment used in wine production, especially for ensuring cleanliness and preventing contamination. For example, DIN standards for surface finishes such as DIN EN ISO 1183 may be applicable to stainless steel tanks and other food-grade equipment [DIN, 2024].

3.4.2 Attachment Point and Tap Size

To create a consistent solution for the majority of fermentation tanks, a common component that was discovered was the racking port. It was discovered to have similar sizes with slight variations, allowing for a promising point of attachment. The most common racking ports were DIN 25 for very small tanks, DIN 40 and DIN 50 which were the most common for tanks 1000 litres and above, and occasionally DIN 32 when converting from DIN 25 to DIN 40.

From the conducted excursions it was also noted that some, though few, fermentation tanks used tri-clamp fittings as an attachment point for racking purposes. The tri-clamps exist in a wider variety of sizes in comparison to DIN [Triclamp, 2024]. Table 4 shows an array of different sizes used on Tri-clamp fittings. Figure 3 explains the measurements in the table.

Table 1: Tri-clamp size chart

Pipe outer diameter (A)	**Flange outer diameter (B)**	**Pipe inner diameter (C)**
1”	1.98”	.87”
1.5”	1.98”	1.37”
2”	2.25”	1.87”
2.5”	3.05”	2.37”
3”	3.58”	2.87”
4”	4.68”	3.83”
6”	6.57”	5.78”
8”	8.57”	7.78”
10”	10.57”	9.69”
12”	12.57”	11.81”

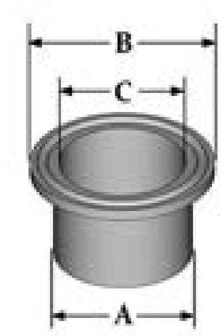

Figure 3: Tri-clamp

An alternative to pumping wine through the racking port was to attach the device through one, alternatively two of the standard taps on the tank, most commonly used for tasting the wine. This alternative was excluded due to complications with occupying a tap that is used regularly by the winemakers. It was also concluded that creating a solution to circumvent this issue was more cumbersome and that the simplest idea was to just use a different entryway. Furthermore, the tap sizes lacked any sort of standard shape, dimension or thread, thus making it difficult to propose a solution that would suit most tanks.

3.4.3 Conclusion of Attachment and Threading

From the conducted excursions it was discovered and concluded that the racking port was the most suitable attachment point for the concept. Thus, a tri-clamp connection, alternatively a threaded connector was deemed viable. Although the tri-clamp attachment is a fair alternative worth considering as a connector, due to its broader alternative of sizes, it was decided that threads are more appropriate in the case of this project. For the final product's purpose, it is of interest to be open to the possibility of fitting a tri-clamp for versatility's sake, as to accommodate for more winemakers.

3.4.4 Resulting Requirements

The mechanical principles of attachment chapter results in three requirements:

- 1.2 Compatible point of connection with existing fermentation tanks
- 5.1 Utilise standardised threads in the following sizes: DIN 25, DIN 32, DIN 40 and DIN 50.
- 5.2 Utilise Tri-clamp fitting

3.5 Pressure Capacity

An important aspect of designing products for use in industrial liquid production is their ability to withstand sufficient operational pressure over time.

3.5.1 Isotropic Pressure in Fluids

The pressure difference p_g over a height difference l is calculated

$$\Delta p_g = \rho g l \tag{1}$$

where ρ is the specific density of the fluid and g is the constant acceleration, or gravity [Francisco J. Arias, 2022]. For simplicity it is assumed that the gravity is always equal 9,82 m/s^2 and that the atmospheric pressure always cancels itself out. According to the hydrostatic paradox, which is itself derived from Pascal's principle, the pressure at a set depth in a homogeneous liquid is always the same, regardless of choice of measurement point [ibid.]. Pressure in a hydrostatic point is therefore solely determined by the depth, or height difference l from the liquid's surface, independent of shape or size of the container or contact area.

3.5.2 Dynamic Pressure in Fluids

Bernoulli's principle describes the ratio of pressure p to flow velocity v and height difference z in a fluid traveling through a constrained vessel. The equation is formulated

$$v^2/2 + gz + p/\rho = constant. \tag{2}$$

According to the principle, by constricting and widening the flow of a fluid, variable pressures can be obtained, different from the static pressure depending simply on depth. The constant relation between these variables assumes incompressibility, laminar flow and zero viscosity in the fluid. Particularly the requirement of laminar flow means that while filling or emptying the fermentation tank the main void of the tank is not subject to the characteristics described by Bernoulli's principle.

In order to avoid the pressure variations created by pumping the wine, potentially resulting in localised pressure peaks, the sensor containing product should ideally be disconnected from any part of the tank or accompanying equipment through which wine flows at a higher velocity and is therefore subject to Bernoulli's principle. Since pumping wine into or out of the fermentation tank is a rare event, primarily done in the racking process [Gunnar Berg et al, 2024], the inability to make measurements during the pumping process is not deemed a major inconvenience.

3.5.3 Specific Density of Wine

Throughout the winemaking process the specific density of the liquid varies over time, usually from a higher to a lower value. The must, or freshly pressed grape juice, is rich in sugar content and therefore has a higher specific density, up to 1 150 kg/m^3. The artificial addition of sugar to the must will increase this number further, as will sulphur additives, but these are usually made at such low rates that essentially no meaningful changes in the specific density occur. Depending on fermentation conditions the yeast will consume differing amounts of sugar and convert it into alcohol, which has a lower density. If given the opportunity to reach complete fermentation, the specific density will stop at as low as 983 kg/m^3 [International Organisation of Vine and Wine, 2009].

3.5.4 Tank Dimensions

Since the pressure at the bottom of the tank directly corresponds to the liquid level in the tank, the height of the tank and therefore maximum liquid level is an important determining factor in the dimensioning of the sensor containing product. According to the definition given in chapter 1.4, a medium-sized vineyard produces up to 75 000 litres of wine annually. However, observations made at wineries indicate that the winemakers opt for multiple smaller tanks, rather than one large to hold the entire yield [Appendix A].

In Appendix A a list of the larger wine tanks observed at wineries and some found on different manufacturers' websites is laid out. Table 2 presents the heights of the different tanks in a more condensed manner.

Table 2: Heights of various fermentation tanks

Brand	**Volume [l]**	**Height [mm]**
Montanaro Fratelli	12 000	3 700
Azzini	7 000	(4 000)
Alva Inox	-	(3 000)
Speidel	2 000	2 940
Gimar Tecno	27 500	6 470
Lainox	5 300	-
Velo spa Altivole-Treviso	-	-
Gimar Tecno	13 400	3 470
SSP	-	(1 500)

According to this data, outliers such as the 6 470 mm tank from Gimar Tecno seem to be less common than the average tank of around 3 000 mm with smaller to medium-sized winemakers. Nonetheless, it is for these extremes accompanying products must be dimensioned. The dimensioning height is therefore chosen as 6 500 mm.

3.5.5 Resulting Value

With a dimensioning height of 6 500 mm and specific density of 1 150 kg/m^3 the pressure difference in the tank is calculated

$$\Delta p_g = \rho g l = 1150 kg/m^3 * 9,82 m/s^2 * 6,5 m = 73,4 kPa. \quad (3)$$

73,4 kPa is the absolute minimum pressure difference a sensor containing product needs to withstand in order to function with the tanks observed during the field studies. In reality, however, circumstances are rarely ideal and some wine maker might decide to attach the product to a taller tank. Other unforeseen events might also contribute to a higher than expected pressure difference. A safety factor is hence needed.

General recommendations for non-vital appliances suggest a safety factor of 1,5 to 2, whilst pressure vessels should have a safety factor of 3,5 to 6 [SafetyCulture Content Team, 2024]. Although technically a pressure vessel, fermentation tanks are rarely externally pressurised and the upper limits of the factor range should be unnecessary. A better way to determine an appropriate safety factor would be to aim for the same or higher pressure capacity as the fermentation tank itself, but since manufacturers are not making such data readily available this method demands further investigation to be utilised. In the meantime an arbitrary safety factor of 2,5 is chosen. This means the dimensioning value rises to 183,5 kPa, or roughly 2 atmospheres.

3.5.6 Conclusion and implications on project

Calculations based on isotropic and dynamic pressure principles, alongside an analysis of specific density variations and typical tank dimensions observed in medium-sized wineries, establish that the product must endure a minimum pressure difference of 73.4 kPa. However, to account for real-world variances and potential unforeseen pressure spikes, a safety factor of 2.5 is applied, raising the design requirement to 183.5 kPa. By adhering to these pressure capacity guidelines, the product will meet the demands of the wine production process, thereby supporting the accurate and safe monitoring of wine fermentation.

The requirement of being detachable during fermentation somewhat limits the possible design choices and mounting positions on the fermentation tank. However, for the purposes of an otherwise open and agile project [Gunnar Berg et al, 2024] this might rather be an advantage in order to move forward in the design process. Detachability from a tank full of wine also imposes a need to attach to already present attachment points, as discussed in Chapter 3.4.

In practice the minimum pressure capacity requirement mainly affects the choice of sealing methods and materials, since the structural components of the product will likely be made out of materials already proven to be suitable for the application and otherwise dimensioned in excess of the safety factor in order to ensure the structural integrity of the product. Additionally the electronic components in direct contact with the wine must to be chosen to ensure complete functionality under pressure.

A potentially major problem with the methodology is the small sample size when it comes to the choice of dimensioning tank. Not all tanks were documented and could be put on the list and most certainly the winemakers visited during the field studies do not use a perfect representation of all the fermentation tanks currently on the market. If further studies indicate that larger wine tanks are commonly in use by the target group the minimum pressure capacity must be increased.

3.5.7 Resulting requirements

The pressure capacity chapter results in two requirements:

- 1.1 Attachable and detachable from tank during fermentation
- 3.1 Minimum pressure difference capacity of 183,5 kPa

3.6 Chemical Resistance

In processes involving acidic or otherwise highly reactive contents, it is important to ensure that the chosen materials are not degraded with prolonged exposure to the reactive substances.

3.6.1 Acidity and pH in Wine

Wine naturally contains various organic acids such as tartaric acid, malic acid and citric acid [Forino et al., 2020]. Furthermore, most artificially introduced sulphur dioxide is converted into sulphurous acid, which, under the right circumstances can oxidise into the more potent sulphuric acid [Norbert Tischelmayer, 2024b]. The presence of these acids in the wine with little to no alkalis to neutralise the solution, results in wine being fairly acidic, with a pH typically ranging from 3 to 4 [Forino et al., 2020].

High acidity can increase the reactivity of certain materials leading to corrosion or leaching of unwanted materials. However, in wine, only the sulphuric acid is considered strong, and even that is very diluted [Jessie A. Key, 2014]. Wine should therefore not be considered a particularly potent acid, and even if materials easily affected by acidity should be avoided, brief contact can be tolerated. Materials only slightly affected by strong acids, although not ideal, can be used for the application.

3.6.2 Alcohol Content

Ethanol is a solvent that can extract compounds from materials it comes into contact with. The higher alcohol content in wine, the major one being ethanol with 9 to 15% per volume, can enhance the extraction of substances from containers and casings, in turn contaminating the wine or leading to unwanted degrading of the container [Revi et al., 2014].

Since alcohol is such a present chemical in wine, no degradation due to alcohol exposure can be tolerated in adjacent materials. All materials affected or slightly affected by alcohol are therefore completely discarded. Although 15% is typically the upper limit of alcohol concentration, runaway fermentation and the artificial addition of sugar can sometimes lead to unintentionally higher concentrations. The threshold is therefore set to 20%.

3.6.3 Aromatics, Aldehydes and Ketones in Wine

Aromatics are a set of hydrocarbons, or organic chemical compounds, which excrete a strong smell. The most common aromatics are benzene, toluene and xylenes [Florida State University, no date]. Being relatively small hydrocarbons, aromatics can, much like ethanol, affect some polymers in a degrading manner. In wine, aromatics contribute greatly to the smell and consequently taste, leading some wines with higher concentrations to be marketed as "aromatic wines".

Aldehydes are organic compounds with the common denominator of having a carbonyl group. Many aldehydes have an odour, which in many cases can be pleasant [Jerry March William H. Brown, 2024]. Most common in wine is acetaldehyde, CH_3CHO, a compound formed during alcoholic fermentation. In low concentrations CH_3CHO does not directly affect the taste of the wine, but does bind to sulphur, which reduces the impact of the sulphur flavor [Norbert Tischelmayer, 2024a]. Much like ethanol and the aromatics, aldehydes being small organic compounds, can extract unwanted compounds from other organic compounds, such as polymers, they come in contact with.

Ketones are similar to aldehydes in their composition, mainly differing in the position of a carbonyl group. In most wines ketones are not present in any larger concentrations, but some white wines and chardonnay in particular receive a large part of their character from ketones [Emely Hodson, 2004]. Although more reactive, ketones similarities with aldehydes extend also to their chemical properties [Bürkle, 2024].

Wine usually contains up to 0,54% ketones and 0,78% aldehydes, although if fermented on lees or aged in oak barrels these values might increase [Veronica Avram et al, 2015]. Aromatics are present in concentrations up to 0,5% [Fengmei Zhu, Bin Du Jun Li, 2015]. Due to these rather low concentrations, none of the chemicals are deemed to have a major effect on the wines chemical behavior, but materials strongly affected by the their presence should be discarded as a safety measure. In order to account for unforeseen events, a safety threshold is set to 1% concentration of each compound.

3.6.4 Cleaning Compounds

During field studies, it was observed that a common product to disinfect wine tanks was chlorine-dioxide, ClO_2 [Appendix C]. Chlorine-dioxide has a broad spectrum for antibacterial activity. Non-corrosive and non-toxic properties make it a popular choice for winemakers for sanitising wine tanks [Selective Micro Technologies, 2023]. Chlorine-dioxide is not regarded as a limiting factor in the choice of material.

Other common cleaning agents are various forms of alkalis. Popular variations include sodium hydroxide, or caustic soda, sodium peroxide [Australian Wine Research Institute, 2024] and sodium carbonate, or soda ash [Grapevine Magazine, 2022]. Out of these sodium hydroxide is the strongest and most potent base [Jessie A. Key, 2014]. Since large amounts of the compound are used at high concentrations no sensitivity to strong bases can be tolerated in the chosen materials. The exact pH of these alkaline cleaning compounds depends entirely on the concentration the winemaker chooses to mix, and it must therefore be assumed that the pH might reach its highest value of 14,0 [Lenntech, no date].

Citric acid is also sometimes used in the cleaning process [Australian Wine Research Institute, 2024]. Although acidic, citric acid is not considered a strong acid and would affect adjacent materials less than the sulphuric acid in wine [Norbert Tischelmayer, 2024b] [Jessie A. Key, 2014].

Some winemakers opt for a chemical free cleaning process. Such practices was observed during the field studies [Appendix B]. Hot or boiling water as well as steam is sprayed into tanks and onto equipment [Australian Wine Research Institute, 2024]. Although chemically inactive, hot water and steam still reach temperatures of 100 °C, which might affect some materials in a degrading manner. Different pressure conditions may cause higher temperatures in some areas. An additional safety margin is therefore added to the requirement, requiring the chosen materials to withstand at least 110 °C.

3.6.5 Suitable Materials

Most glass types are promising, as long as they are not too brittle, porous or prone to thermal shock. The choice of glass is thus left open to many possibilities [Roe Li, 2023]. What can be worth noting is that there are some glass types worth avoiding. This may be because their properties are deemed excessive in contrast to their cost or production. For instance, tempered glass may be unnecessary unless specific strength requirements justify its cost and use. Leaded glass is also recommended to avoid due to toxicity concerns.

The most commonly found material in wine making equipment as of today is stainless steel, and it is a commonly used material in most food and beverage processing for good reason. The hardness and ductility of the material allows for the creation of long lasting smooth and non-absorbent surfaces. As the name implies, the material is also highly corrosion-resistant, forming a chromium-rich protective film in the presence of oxygen.

No measurable chemical reaction normally occurs between stainless steel and most beverages, but the higher than otherwise normal presence of sulphur dioxide, and during cleaning, chlorine-dioxide causes some issues. This is mitigated by adding about 2% molybdenum to the alloy, so called 1.4401 or AISI 316 steel, making it suitable for contact with wine [Eric Partington, 2006]. The alloy complies with the Framework Regulation (EC) 1935/2004 [Ekaterina Karamfilova, 2016]. Furthermore, stainless steels resist thermal shock well, although deforming more with temperature changes than some other materials such as glass and many plastics. [Eric Partington, 2006].

The third major group of materials generally considered suitable for applications such as this is plastics, or polymers. Table 3 displays the chemical resistance of a number of construction polymers to various relevant chemical corrosives. The data was put together by Bürkle, an industrial appliances manufacturer. The company's focus on chemical sampling equipment should align their methods with the purposes of this thesis.

Tests were performed for 30 days at 20 degrees Celsius [Bürkle, 2024]. These conditions roughly represent the environment a winemakers equipment will be subjected to during fermentation [Gunnar Berg et al, 2024]. During prolonged ageing, some of the materials may experience degradation not included in this table, and in order to prevent this potential problem a recommendation should be issued to the user not to leave the measuring unit connected to the tank after fermentation has stopped if any of these materials are used in the final product. However, according to interviews, continuous monitoring of the wine after fermentation has stopped is not necessary [Appendix B].

"-": *No Data*, "N": *Not Affected*, "SA": *Slightly Affected*, "A": *Affected*

Table 3: Chemical resistance of certain polymers

Polymer	**Strong Acid**	**Strong Base**	**Aromatics**	**Alcohol**	**Ketone**	**Aldehyde**
ABS	N	N	A	SA	SA	SA
LCP	SA	SA	N	N	N	-
PA	A	N	N	N	N	N
PAI	N	A	N	N	N	-
PBI	A	A	N	N	N	-
PBT	N	SA	SA	N	N	N
PC	N	A	A	N	A	A
PEEK	SA	N	N	N	N	-
PEI	N	A	SA	N	N	-
PET (CF30%)	N	SA	SA	N	A	A
PI	SA	A	N	SA	N	-
POM	A	A	N	N	N	N
PP (talc40%)	N	N	A	A	N	N
PPA	SA	N	N	N	SA	-
PPE based resin	N	N	A	A	A	A
PPS	N	SA	N	N	N	-
PPSU	SA	SA	SA	SA	A	-
PSU	SA	SA	A	SA	A	-
PTFE	N	N	N	N	N	-
PVDF	N	SA	SA	N	SA	-

3.6.6 Conclusion and implications on project

The selection of materials for the continuous monitoring unit in wine fermentation must account for the chemical environment of wine, which includes acids, alcohols, aromatics, aldehydes and ketones. Various cleaning agents are also considered. Wine's acidity, with a typical pH of 3 to 4, necessitates materials that are not easily corroded or degraded by organic acids like tartaric, malic, and citric acids, or by the more potent sulphurous acid. Although wine is not considered highly potent in its acidity, materials should still be carefully selected to avoid degradation. Ethanol, present in wine at concentrations of 9 to 15%, with a safety threshold set at 20%, is a strong solvent that can extract compounds from materials. Therefore, materials in contact with wine must exhibit complete resistance to alcohol degradation.

Cleaning agents used in wine making, such as chlorine-dioxide, sodium hydroxide, and citric acid, introduce additional constraints. Sodium hydroxide, in particular, can reach pH levels up to 14, requiring materials that are completely resistant to strong bases. Hot water and steam used in chemical-free cleaning processes demand materials that can withstand temperatures of at least 110°C to prevent thermal degradation.

Among the suitable materials, most glass types are promising due to their chemical inertness and durability. However, tempered glass and leaded glass should be avoided due to cost and toxicity concerns. Plastics and metals also offer viable options, with specific polymers such as PEEK, PPA and PTFE demonstrating varying degrees of resistance to all the chemicals in question. Table 3 provides a comprehensive overview of the chemical resistance of various construction polymers. However, materials may still experience degradation over extended periods, emphasising the importance of not leaving the measuring unit connected to the tank post-fermentation.

In summary, the selection of materials for the wine fermentation monitoring unit requires careful consideration of their chemical resistance to ensure long-term durability and safety. Further research and testing may be needed to explore additional materials and to refine the design for optimal performance in the winemaking environment. Design choices concerning internal geometries and manufacturing requirements may further exclude many of the material candidates, regardless of their suitability from a chemical standpoint. Another potential approach regarding the inertness to cleaning compounds, which needs to be explored, would be to issue a series of recommendations on which compounds and methods should be used, rather than making a product compatible with all. Removing the requirement to resist strong bases would for example include LCP, PAI, PBT, PEI, PPS and PVDF in the list of approved polymers, a rather drastic increase in the amount of suitable materials, highlighting the potential flaws with this conclusion as a whole.

3.6.7 Resulting requirements

The chemical resistivity chapter results in 7 requirements:

- 1.4 Service cycles of at most 30 days | In order to ensure material stability
- 3.1 Resistant to pH 2,5 to pH 14 | Alternatively limit cleaning methods
- 3.2 Inert to alcohol at 20% concentration
- 3.3 Inert to strong bases | Soda ash, Sodium carbonate, sodium peroxide
- 3.4 Somewhat inert to trace organic compounds at 1% concentration | Aromatics, ketones and aldehydes
- 3.5 Somewhat inert to strong acids | Sulphurous acid
- 4.2 Thermally stable at 110 °C

Although not a requirement, a recommendation is issued to use a selection of the following materials in future projects: Various non porous glasses, AISI 316 stainless steel and PEEK, PPA and PTFE plastics.

3.7 Sanitation and Maintenance

3.7.1 Abrasion

The product must demonstrate sufficient resistance to mechanical abrasion during the cleaning process to prevent material degradation and ensure long-term durability. Compliance will be verified through standardised testing methods, such as the Taber Abrasion Test, confirming that the product retains its structural and functional integrity after exposure to routine cleaning abrasions. The Taber wear test uses an instrument to accelerate wear to evaluate a material's wear resistance.

Taber Wear Index indicates the rate of wear, and is calculated by measuring the loss in weight (in milligrams) per thousand cycles of abrasion. The lower the wear index, the better the abrasion resistance [Taber Industries, no date].

The equation for calculating the Taber Wear Index is as follows:

$$I = [(A - B) * 1000]/C \tag{4}$$

where I = *wear index*
A = *weight (mass) of specimen before abrasion*
B = *weight (mass) of specimen after abrasion*
C = *number of test cycles*

In general, materials used in food and beverage production, including wine fermentation, should exhibit excellent durability and resistance to wear. To ensure the durability and performance of materials used in wine fermentation, all equipment must pass the Taber Abrasion Test with a Taber Wear Index of no more than 20 mg/1000 cycles. This means that the material should not lose more than 20 milligrams of weight after 1000 cycles of abrasion. Only materials meeting or exceeding this level of abrasion resistance will be considered suitable for use. This excludes sensors and sensitive measuring units that may require separate cleaning.

3.7.2 Resulting Requirements

The sanitation and maintenance chapter resulted in the requirement:

- 6.1 Pass Taber Abrasion Test with $<$ 20 mg/1000 cycles

3.8 Additive Manufacturing

This section explores the possible use of additive manufacturing in the context of food safety.

3.8.1 Available Techniques

FDM
Fused deposition modelling is an AM technique that uses a layer-by-layer method to produce the desired form. Capable of using a multitude of different filaments, allowing it to be very versatile. By injecting a string filament into a heated unit, it can be extruded through a nozzle as a malleable material that quickly hardens and retains its shape.

SLA
Stereolithography is a 3D printing method that uses a UV projector and selective LCD mask to harden a resin in layers.

SLS
Selective laser sintering uses high-powered lasers to sinter or bind finely powdered material together into a solid structure.

3.8.2 Selected Materials Working Temperature

Common filaments used in additive manufacturing and their maximum working temperature before the material starts to deform under load [Simplify3D, no date].

Table 4: AM-filament maximum working temperature

Material	**Maximum service temperature**
ABS	98°C
PLA	52°C
PETG	73°C
Nylon	80-95°C
ASA	95°C
Polycarbonate	121°C
HIPS	100°C

3.8.3 Cost and Production

Using AM techniques, compared to CNC-machining, the cost of certain parts can be cut significantly for small to relatively large production volumes. Adding intricacy and reducing weight without large increases in cost.

3.8.4 Potential Problems and Mitigations

Most FDM-printer nozzles are made of brass, which may leave traces of lead in very small doses. The nozzle would therefore need to be swapped out to a stainless steel nozzle to nullify the risk of lead contamination.

PETG is a common food safe material that can for instance be found in PET bottles. PETG is a thermoplastic that can be used in FDM-printers. With the correct setup, PETG can be food-safe. The issue resides in the FDM technique that is used. FDM results in layer lines that leave pockets for bacteria to collect. To circumvent this issue, the part must be post-processed to ensure that it can be sufficiently cleaned after each use. It should be noted that coatings do not guarantee food safety [Formlabs, 2023].

A potential issue with using thermoplastics is its maximal working temperature. Depending on the application of the plastic part, and including the safety factors in the calculation, the working temperature may exceed what the part is capable of tolerating.

SLA printers use a thermosetting resin, which in most cases is toxic [Melanie Griffin, 2024]. There are instances where resin is biocompatible and used in dental contexts, but this does not mean that the resulting product is food-safe, or even food-grade for that matter [Formlabs, 2023].

An issue that may occur with FDM is waterproofing. It may be difficult to ensure that the printer lays down fully intact layers with no gaps. Without any post-processing of the product, creating a waterproof FDM print is highly unreliable. Waterproofing can be achieved with dichtol, a chemical that seals and impregnates 3D printed parts. However, the food compatibility of this material needs to be further studied.

3.8.5 Result and Conclusion of Additive Manufacturing

Through conducted research it is concluded that the use of AM techniques is not suitable for direct food contact, as achieving food-safe parts is deemed less plausible. Furthermore the working temperatures of most filaments do not reach high enough for them to be considered for for parts that are exposed to the sanitation requirements. However, AM is still highly relevant for constructing the housing and selected outer parts of the unit, considering that the temperature should be significantly lower, thus allowing the filament to be within acceptable limits. It is therefore still valid to consider additive manufacturing for cost-effective and accessible production of parts that are not in contact with the wine.

3.8.6 Resulting Requirements

The additive manufacturing chapter resulted in the requirement:

- 1.3 Additive manufacturing | Not suitable for direct food contact, though promising for other parts such as casing, etc.

3.9 Fluid pumps

The concept *Pump on the Tank*, see Chapter 3.2, requires wine to be pumped out of and back into the fermentation tank. Since this function is central to the concept, great deliberation should be put into the choice of pumping mechanism, of which there are many possible candidates.

3.9.1 Centrifugal pumps

By far most common pumping mechanism on the market is the centrifugal, or rotodynamic, pump [Castle Pumps, 2024]. The pump operates by spinning an impeller to transfer the kinetic energy of the impeller to the fluid in a radial motion. As the impeller rotates, it draws in fluid through an intake point, accelerating it radially moving the fluid to the discharge point at a higher pressure. Centrifugal pumps largely make up the category of non-positive displacement pumps [Global Pumps, 2024a].

Being so widely used, centrifugal pumps are readily available in many shapes and sizes. They also come at a low cost in relation to displacement volume and have a comparatively compact design. Pressures generated are typically high, especially at their optimal fluid viscosity, and this makes centrifugal pumps a suitable choice for heavy duty applications such as fuel transferring, sea water pumping and sewage systems [Castle Pumps, 2024].

One of the main downsides of centrifugal pumps is their inability to run dry, This not only potentially damages the pump due to lack of resistance and rotational speeds exceeding the upper safe value, but also fails to build up enough pressure to pull liquid up into the pump if filled with air. This creates the need for an external so called priming pump to get the system started. Solid particles in the fluid may also harm the pump [Global Pumps, 2024a]. Another issue with centrifugal pumps is that several mechanical components and seals are in contact with the fluid during operation. This does not affect the pump during operations, but increases the number of parts that need to be cleaned between use cycles when used in food and beverage processing.

3.9.2 Positive displacement pumps

Positive displacement pumps is the collective term for pumps trapping fixed volumes of fluid, usually in a cavity, and then forcing that volume through the discharge point. The many varieties of positive displacement pumps are divided into two main categories, reciprocating and rotary pumps. Reciprocating pumps, typically operating by some sort of piston or diaphragm principle, generate an oscillating pressure output, whereas rotary pumps output a constant pressure and flow rate [Michael Smith Engineers, 2024a]. Since reciprocating pumps are typically more advanced and less space efficient whilst not offering any additional benefits to the functionality of the product, these are henceforth discarded.

Rotary positive displacement pumps come in many variations, but all share the common attribute of a rotationally non-symmetrical driving mechanism creating, shifting and opening up fluid filled cavities. Other common denominators include that all positive displacement pumps are to some degree self-priming and that they are not affected by differing fluid pressures [Global Pumps, 2024a]. Some of the most common types of rotary positive displacement pumps include the following list. Figure 4 displays a schematic of the different pump types [GUNT, 2024].

Gear pumps:
Gear pumps consist of two internally constrained gear interlocking and rotating counter-clockwise. Fluid is caught between the teeth of the gears and the casing and is forced to rotate with the gears. By sealing the intake and outlet cavities the gears force fluid around themselves from one side to another. Gear pumps typically operate at a relatively low flow rate, but offer a compact design and high energy efficiency. Furthermore, gear pumps are reversible, allowing for easier cleaning and higher sanitary standards [Global Pumps, 2024c].

Rotary piston pumps:
Also referred to as lobe pumps, rotary piston pumps are similar to the gear pumps in many aspects. The primary difference lies in the amount of teeth, typically being three instead of the many more in gear pumps. Thus, rotary piston pumps share most characteristics with gear pumps, with the addition of being less sensitive to solids and highly viscous fluids as well as offering a higher flow rate [Global Pumps, 2024c].

Vane pumps:
A vane pump consists of vanes mounted radially on a cylindrical rotor, which is eccentrically located in a casing. The two types of vane pumps are sliding vane pumps and flexible vane pumps. In the case of sliding vane pumps the vanes glide freely through radial slots in the rotor, being forced outwards against the casing at high enough speeds. Flexible vanes form a seal by maintaining tension through bending against the casing. Vane pumps are best suited for low viscosity and clean fluids, containing very low amount of solid particles. They are also more prone to leaking than other types of positive displacement pumps [Michael Smith Engineers, 2024c].

Impeller pumps:
Unlike the impeller in a centrifugal pump the impeller of a positive displacement impeller pump is not rigid, but rather flexes to conform to the geometry of the casing, similar to a flexible vane pump. As the impeller shaft is mounted ec-

centrically in the casing, the flexing impeller blades will alter the volume of the cavities in between each other as they rotate, drawing the fluid in and pressing it out in a controlled manner.

Peristaltic pumps:
In a peristaltic pump a flexible tube is fixed between the casing and a rotor. The rotor utilises a set of either rollers or shoes to squeeze the tube at a number of locations, creating cavities in which fluid is trapped. The flexible tube constrains the fluid and acts as both the intake and outlet point [Michael Smith Engineers, 2024b]. Peristaltic pumps typically produce low flow rates, but operate with high energy efficiency. The simplicity of the design not only mean that the fluid is completely contained to one component, thereby making the system easier to clean, but also allows for lower prices and a decreased need for maintenance. Peristaltic pumps also offer completely reversible operations and the inherent flexible nature of the tube allows for solid particles to pass through the system without problem [Global Pumps, 2024b].

Figure 4: Schematic of some rotary positive displacement pumps

3.9.3 Conclusion and implications on project

A number of fluid pumping mechanisms have been examined for their unique properties, each displaying some advantages and disadvantages compared to one another and different use cases. However, the choice of the appropriate pumping mechanism for maximum efficiency and reliability of a product for wine fermentation monitoring should be made with the specific environment and conditions of pumping wine in mind.

Firstly Requirement 1.1, to be attachable and detachable from pipes during fermentation, introduces the problem of attaching an air filled product to liquid filled system. This demands of the pump to be self priming in order to function properly. Secondly, in order to comply with all relevant health and safety regulations, see Requirement 2.1 to 2.5, the pump should allow for easy cleaning and disassembly. Finally the concept requires the sensor containing product to operate by battery power, according to Requirement 1.4 in service cycles up to 30 days. This demands that the pump is energy efficient at the required flow rates, which although unspecified, can be assumed to be relatively low.

Peristaltic pumps, although producing lower flow rates, stand out for their energy efficiency and simple design, which ensures that the fluid is completely contained within one component, simplifying the cleaning process and reducing maintenance needs. They also fulfill the requirement of being self priming. This makes them particularly appealing for applications requiring high sanitary standards.

In conclusion, while centrifugal pumps are widely used and effective in many industrial applications, positive displacement pumps, especially peristaltic pumps, offer distinct advantages for the specific requirements of wine production. Their ability to handle solid particles, self-priming nature, and ease of cleaning make them a more suitable choice for integrating into a sensor-containing product for monitoring of the fermentation process. Future considerations should include a detailed cost-benefit analysis and real-world testing to validate the suitability of the chosen pump type under operational conditions.

3.9.4 Resulting requirements

The fluid pump chapter results in the requirement:

- 5.3 Use pump with self-priming ability
- 5.4 Use pump with high energy efficiency
- 5.5 Use pump with reversible operation
- 5.6 Use pump with easily cleaned and removable parts

Although not a requirement, a recommendation is issued to use a peristaltic pump of low diameter to ensure a reliable, energy efficient and sanitary system.

4 Synthesis

The synthesis summarises the individual conclusions and implications on the project from all chapters in the analysis phase.

4.1 Summarised Results

This section compiles the accumulated results from the analysis phase. These results are gathered and further developed to derive a meaningful outcome, presented in this section.

4.1.1 Summarised Requirements

Table 5 summarises all requirements from the analysis phase.

Table 5: Summarised Requirements

No.	Requirement	Comment
1.0	**Application**	
1.1	Attachable and detachable from tank during fermentation	
1.2	Compatible point of connection with existing fermentation tanks	If threaded, DIN is recommended, else tri-clamp fitting
1.3	Do not use additive manufacturing for part intended for direct contact with wine	Not suitable for direct food contact, though promising for other parts such as casing, etc.
1.4	Service cycles of at most 30 days	In order to ensure material stability
2.0	**Standards and regulations**	
2.1	Comply with EHEDG guidelines	Surface finishes and hygienic design principles
2.2	Comply according to EC 1935/2004	Ensures that no harmful substances transfer to the food
2.3	Comply according to ISO 4439:1979	Ensures vinyl tubing is food grade
2.4	Comply according to EN ISO 4892-2:2013	Standard to ensure plastic's Resistance to UV-induced degradation
3.0	**Chemical resistance**	
3.1	Resistant to pH 2,5 to pH 14	Alternatively limit cleaning methods
3.2	Inert to alcohol at 20% concentration	
3.3	Inert to strong bases	Soda ash, Sodium carbonate, sodium peroxide. Alternatively limit cleaning methods
3.4	Somewhat inert to trace organic compounds at 1% concentration	Aromatics, ketones and aldehydes

Continued on next page

Table 5 – continued from previous page

No.	Requirement	Comment
3.5	Somewhat inert to strong acids	Sulphurous acid
4.0	**Physical restraints**	
4.1	Minimum pressure difference capacity of 183,5 kPa	
4.2	Thermally stable at 110 °C	Without compromising the structural, and chemical integrity of the material
5.0	**Mechanical Principles**	
5.1	Utelise standardised thread sizes	DIN 25, DIN, 32, DIN 40, DIN 50
5.2	Utelise Tri-calamp fitting	Utilised if it is deemed more prominent for the specific case
5.3	Use pump with self-priming ability	
5.4	Use pump with high energy efficiency	
5.5	Use pump with reversible operation	
5.6	Use pump with easily cleaned and removable parts	
6.0	**Material Aspects**	
6.1	Pass Taber Abrasion Test with $<$ 20 mg/1000 cycles	Concerns components in contact with wine

4.2 Summarised Discussion

The intention is to, with the assistance of the requirement list, develop a morphological matrix for future developments of products with similar purpose. Depending on the development of the product, some requirements become more pertinent than others, while some might even become irrelevant. Therefore, standards and regulations may have a bigger impact in some cases than others. Likewise for the choice of connecting fitting, being a threaded DIN or Tri-clamp, the utilisation depends on the case and what is deemed most appropriate.

These requirements are set as a baseline to guarantee a product that is functionally and structurally operable. They are set with the intent that the product should be subject to the same cleaning requirements as most other brewing equipment, however, these requirements can be altered to accommodate for different solutions. For instance, limiting cleaning methods specifically for the unit to facilitate the use of a less chemically resistant, but cheaper or more readily available material.

4.3 Conclusion

The concluding chapter tries to determine whether the research questions were properly answered and what future work might lie ahead if the decision should be made to move forward with the development of the sensor containing product.

4.3.1 Answers to Research Questions

The main problem statements are:

1. What are the requirements and limitations for the product to be successfully incorporated into existing wine making equipment?
2. What mechanical principles could be utilised to achieve these requirements, and how does this affect the choice of materials?

The established requirements and limitations that answer to problem statement no.1 are displayed in table 5.

As the concept *Pump on the Tank* demands circulation of wine for its functions, a pump is thus deemed necessary. The placement of the pump then leads to physical requirements that need to be addressed, as stated in Chapter 3.5.5, creating a threshold of what is required for the pump to operate without fail.

It is clear that the main aspects that governs whether the product can be successfully incorporated into winemaking is its compatibility and approval of food safe materials. Ensuring a suitable surface finish and a material that is safe to be in contact with the wine are compulsory requirements to achieve a successful and approved product.

Mounting the unit on the outside of the tank, opposed to submerging it, poses different difficulties. If submerged, the entirety of the device would be subject to waterproofing requirements. By opting to mount it externally, we can circumvent this issue by properly sealing the electronics from the sensors. This in turn widens the possibilities of appropriate materials following that all parts no longer are subject to waterproofing requirements.

In the case of *Pump on the Tank*, the incorporation into existing winemaking equipment relies on attachment points and entries on the tank. Meaning that one of the utilised mechanical principals for this device would be threaded attachment. This in turn sets requirements for the product. For instance, attaching the device to the racking port implies that the device must withstand a pressure according to the water pillar above it. This, along with all other design choices following the requirement list sets the criteria for what materials are suitable.

Although additive manufacturing seemed promising for use in the sensor containing product, it is concluded that achieving and maintaining a food safe finish with a food safe material without jeopardising its structural and chemical integrity was not currently possible. It is though, deemed fit to construct the housing and selected outer parts, thereby widening the possible production techniques, and simultaneously widening the possibility for new materials.

However, due to the nature of the research questions and the project as a whole, even with a way more comprehensive scope, the solution space is infinitely large and could not be completely explored. Whilst impossible to cover all materials, applicable mechanical principles and possible solutions to the proposed problems, the report provides some important insights into an enormous topic, hopefully saving the people taking the development of the product further time and resources. It is therefore the authors view that the research questions were adequately answered and that the conclusions are a good ground for further investigation.

4.3.2 Future Work

Further areas of interest that should be studied are the possibilities of waterproofing currently unfit materials, exploring a solution to make FDM-prints food safe, light weighting of the concept and further developing the physical design of the device itself.

Another point of interest could be to develop the product to ensure fail safes and reconstruct it in a way that ensures that if one part breaks, that the entire product is not rendered unusable or causes a major leak.

Extended research regarding material sustainability is also something that should be studied further. To better recommend materials that are appropriate and likewise to inform what materials that should be avoided. This can be done by investigating the users' interactions with the product to understand what areas need reinforcement, what materials that are better fit, and to understand what parts are subject to regular wear.

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Appendix A

Brands and dimensions of wine tanks observed at wineries.

Brand: Montanaro Fratelli
Observed at: Salvan Vineyard
Volume: 12 000 l
Height: 3 700 mm
URL: https://montanarofratelli.com/en/product/fiberglass-tanks-variable-capacity-firm-coplar-capacity-hl-100-second-hand-equipment/
(closest product on market)
Last accessed: 2024-04-26

Brand: Azzini
Observed at: Salvan Vineyard
Volume: 7 000 l
Height: 4 000 mm (estimate from similar tank)
URL: https://montanarofratelli.com/en/product/stainless-steel-tank-capacity-liters-5000-hl-50-azzini-brand-storage-winemaking-model-second-hand-equipment/ (similar tank of same brand)
Last accessed: 2024-05-21

Brand: Alva Inox
Observed at: Salvan Vineyard
Volume: (unknown)
Height: 3 000 mm (estimate from picture)
URL:
Last accessed:

Brand: Speidel
Observed at: Thora Vineyard
Volume: 2 000 l

Height: 2 940 mm
URL: https://brouwland.com/en/fermentation-vessels/837-speidel-fermentation-tank-fs-mo-2000-litres.html
Last accessed: 2024-05-02

Brand: Gimar Tecno
Observed at: Ca Lustra Vineyard
Volume: 27 500 l
Height: 6 470 mm
URL: https://www.gimardt.it/en/catalogue-products/tanks-pressure-tanks-fermentation-tanks/stainless-steel-tanks
Last accessed: 2024-05-21

Brand: Lainox
Observed at: Ca Lustra Vineyard
Volume: 5 300 l
Height: (unknown)

URL:
Last accessed:

Brand: Velo spa Altivole-Treviso
Observed at: Ca Lustra Vineyard
Volume: (unknown)
Height: (unknown)
URL:
Last accessed:

Brand: Gimar Tecno
Observed at: Salvan Vineyard
Volume: 13 400 l
Height: 3 470 mm
URL: https://www.gimardt.it/en/catalogue-products/tanks-pressure-tanks-fermentation-tanks/stainless-steel-tanks
Last accessed: 2024-05-21

Brand: SSP
Observed at: Särtshöga Vineyard, Åhus Vineyard
Volume: (unknown)
Height: 1 500 mm (estimate from picture)

URL: http://www.ssp-edelstahlprodukte.com/products/stainless-steel-tanks-wineries
Last accessed: 2024-05-21

Appendix B

Figure 5: Interview summary from Cà Lustra Vineyard

Appendix C

Figure 6: Interview summary from Salvan Vineyard