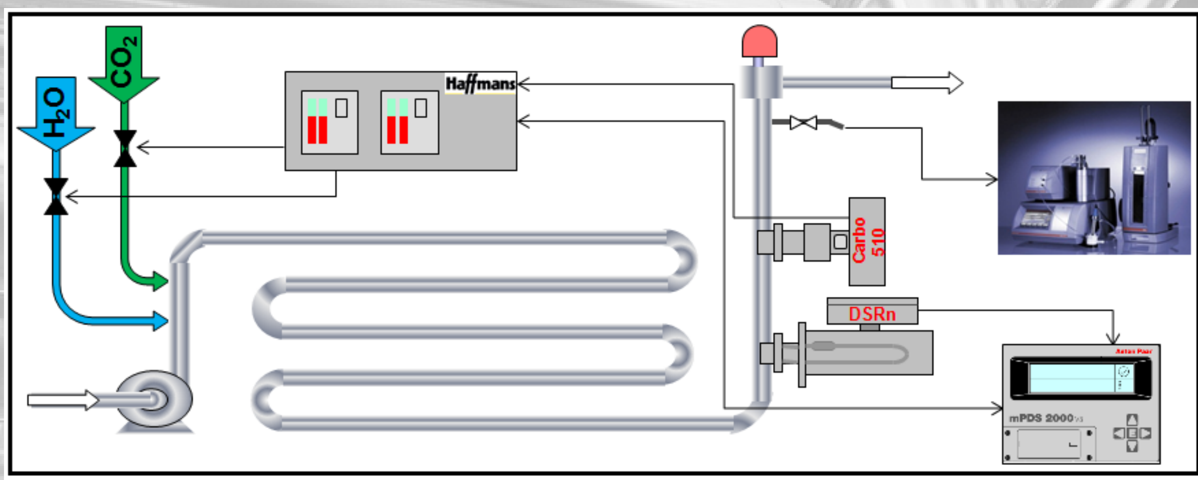
Bachelor Thesis

ANALYSIS OF THE FILTRATION PROCESS AT A BEER BREWERY



NINA RUSCH

Grolsch

KONINKLIJKE *GROLSCH* N.V.

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A *SABMiller* Company

Brouwerslaan 1
7548 XA Enschede
Tel: +31(0)53-4833333
www.koninklijkegrolsch.nl

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Author	Nina Rusch s1411802 nina.rusch@web.de
Bachelor Program	Industrial Engineering and Management
Graduation Committee University of Twente	Dr. ir. L.L.M. van der Wegen *Faculty of Behavioral Management and Social Sciences* Ir. Arturo E. Pérez Rivera *Faculty of Behavioral Management and Social Sciences*
Grolsche Bierbrouwerij	Harro de Vries *Manager Brewing*

MANAGEMENT SUMMARY

The Brewing Department at *Grolsch* is responsible for brewing and filtering beer for their customers. During the filtration process a few problems were identified with the main problem being the inaccurate measurements of the inline instruments, thus of the alcoholic strength and the original extract. The measurement of these parameters is of importance in order to offer the customers high quality products. Therefore, the main research question discussed in this thesis is identified as:

How can the inaccurate measurements of the inline instruments within Brewery Grolsch's filtration process be improved?

During the research multiple possible causes are identified and nine are analyzed in more detail. From interviews with mainly the operators of *Grolsch* but also employees of the company *Anton Paar*, which produces most of the inline instruments, the main causes are identified and evaluated. The four main causes are the product-specific adjustment, reaction time, important parameters and the batch size. The root causes behind the main problems are investigated for each cause individually. In the end, recommendations for improvements and future research are written.

Product-specific adjustments involve the product numbers used during the filtration process and the adjustment of the inline instruments with laboratory values as reference. In cooperation with the company *Anton Paar*, the inline measurements are better analyzed and the adjustment procedure is reviewed. In the end, irregularities are found and two options for new allocation of the numbers as well as a new adjustment procedure are proposed. This is something *Grolsch* has wanted to do for quite some years. The reaction time involves the time that instruments need to adjust to the manually changed values in the automation system or to the fluctuating process conditions. Some of the valves have problems with those adjustments. Many parameters can be changed to adjust them. In order to detect the problems behind the irregularities or long reaction time of valves faster, a new valve irregularity procedure is recommended. Next, the important parameters are part of another problem behind the inaccurate measurements. During different phases of the brewing and filtration process, different parameters are of importance. Especially the inline pressure during the measurement process is of importance. It is noticed that the Beer Pressure Regulating Valve, which is responsible for establishing a consistent inline pressure, has no set-point installed and therefore does not regulate the process flow. In consultation with the company Haffmans, a recommendation for the set-point range for the valve is made. It is further recommended to measure the optimal set-points for different product types and product packaging families, since the CO_2 content of those differs. Finally, it is identified that some of the batches are too small to produce an end product within the range of the quality standards. The batch sizes are dependent on the demand of the customers and the shelf-life of the products. Products with low demand and shelf-life have to be produced in smaller batches. Moreover, the minimum batch size has never been calculated but is an estimate. For the future, calculations per product are recommended. Through implementing the recommendations, a more stable and efficient process will arise.

General recommendations for *Grolsch* are to improve the knowledge of the process and process conditions by letting employees read the instruction manuals and by organizing trainings. Also a preventative maintenance routine is recommended in order to find problems and irregularities earlier. The most important of all, is the introduction of Knowledge Management. This involves knowledge sharing and expanding the knowledge of employees in order to have more specialists in all necessary fields. It also involves better documentation of processes, outcomes and routines. The research is limited to the analysis. *Grolsch* has to choose which solutions should be implemented.

PREFACE

How is beer made? Most people immediately think about the brewing process and how the beer is finally filled into bottles or kegs. Many do not know anything about the filtration process and about process and quality control. This research shows that brewing beer is a complex process and many factors are important for delivering high quality products to the customers.

This research would not have been possible without the help of many people. For the past ten weeks I worked at *Grolsch* in the Brewing Department. This gave me the opportunity to experience beer brewing in a way I have never before. My knowledge about the brewing process was non-existing until I started working there. During the period of my research, there were always employees who helped me with my questions and had the patience to explain the processes to me in much detail. They also provided information for me and gave feedback on my ideas. The friendly environment made the work exciting and interesting. Besides all the employees at *Grolsch*, also employees from the companies that produce the inline instruments helped me when possible. I thank all the people who made this research possible.

During this research two supervisors supported me. First my supervisor at *Grolsch*, Harro de Vries. He guided me through the research, gave me feedback and discussed and evaluated my ideas with me. His door was always open for me. From the university Leo van der Wegen supported me. He always made time to give me stimulating advice and feedback. Thank you for your constructive evaluations and advice.

Finally, I would like to thank my friends, roommates and family for the continuous support even in the stressful times of the research.

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FIGURES, TABLES AND EQUATIONS

LIST OF ABBREVIATIONS

Abv	Alcohol by Volume
BBT	Bright Beer Tank
BPRV	Beer Pressure Regulating Valve
Carbo 510	*Anton Paar* Carbo 510
CO_2	Carbon Dioxide
DSRn 427	*Anton Paar* DSRn 427
FBT	Filtered Buffer Tank
KG	Kieselguhr
mPDS	*Anton Paar* mPDS 2000V3 Evaluation Unit
O_2	Oxygen
OE	Original Extract
PLC	Programmable Logic Controller
PVPP	Polyvinylpolypyrrolidone
UBT	Unfiltered Buffer Tank

GLOSSARY

Anton Paar	*Anton Paar* GmbH produces high-quality measuring and analysis instruments for research and industry.
Automation System	Automated systems eliminate the need for human interference in order to complete a task.
Beer Monitor	The Beer Monitor is responsible for determining all beer parameters through combined density and sound velocity measurements.
Brewing Department	The Brewing Department is responsible for brewing and filtering all beers at *Grolsch*.
Brewmaxx	*Brewmaxx* is a process control system for the brewing industry in which various process steps of a brewery are automated, controlled and monitored.
Condition-Based Maintenance	Condition-Based Maintenance only performs maintenance when the facilities require it
Continuous Improvement	Continuous Improvement is the seeking of small incremental improvement steps in processes and products, with the objective of increasing quality.
Degree of Clarity	The dullness of the beer.
Depth-Filtration	Depth-Filtration works by collecting particulates within the filter medium and passing a clean outlet flow of the beer.
Diatomaceous Earth	Diatomaceous Earth is a fine siliceous earth composed chiefly of the cell walls of diatoms and used in filtration.
Filtration Process	The Filtration Process is an operation during the beer production that separates solids from fluids by directing it through a medium which only fluids can pass.
Focused Improvement	Focused Improvement is the process of applying systematic problem solving methods to manufacturing

Haffmans Numbers	The product numbers at *Grolsch* are called Haffmans numbers and are of importance for the accuracy during the measurements.
High Gravity Brewing	During High Gravity Brewing the original extract is significantly higher than the target and during filtration it is diluted with water.
Ishikawa Diagram	Ishikawa diagrams are causal diagrams that show the causes of a specific core problem.
Kieselguhr	Another word for Diatomaceous Earth.
Knowledge Management	Knowledge management is the process of effectively capturing, developing, sharing, and using the knowledge of an operation.
Lager Beer	Lager beer is a type of beer that is conditioned at low temperatures and has not yet been filtered.
Methodological Triangulation	Methodological Triangulation is a method that checks and double-checks its solutions in order to validate the data.
Original Extract	Original Extract is the amount of extract(sugar) in the beer before fermentation.
Pasteurization	Pasteurizing is a process that kills bacteria in liquid foods by heating the liquid.
Permeability Factor	The permeability factor of a filter describes the pressure differential across the filter bed.
Planning Department	The Planning Department at *Grolsch* is responsible for all planning processes important for the end product.
Polyvinylpolypyrrolidone	Polyvinylpolypyrrolidone is used as a filter medium in the brewing industry. It removes polyphenols in beer production and thus clear beers with stable foam are produced.
Preventive Maintenance	Preventive Maintenance eliminates the chance of a possible failure by checking, cleaning and replacing the instrument parts regularly in pre-planned intervals.
Process Control	Process Control means controlling all processes throughout the brewery. If all processes harmonize the company can succeed.
Product-Specific Adjustment	The product-specific adjustment is an action that brings a measuring instrument into a state of performance, suitable for its purpose. It means minimizing the measurement errors as well as deviations by adjusting the measuring instrument.
Proleit	*Proleit* is a company specialist in process control systems and automation solutions for the brewing industry.
Quality Control	Quality Control is the process of reviewing the quality of all factors involved in the production of beer.
Quality Control Department	The department responsible for Quality Control.
Run-To-Breakdown Maintenance	Run-To-Breakdown Maintenance means allowing the instrument to continue working until it fails and then repair or replace it.
Shelf-Life	Shelf life is the length of time that beers may be stored without becoming unfit for consumption or sale.
Silica Gel	Silica Gel is a beer stabilizer that is used during filtration and which reduces the level of haze that can form in the finished beer.
Sludge Capacity	The amount of filter-aid which can be added during a filter run.

1. INTRODUCTION

The *Grolsch* brand, as well as the process of brewing beer, has changed throughout the years. Whereas back in the days, the master brewer had to control the process manually, nowadays an automated system, also called *automation system*, does most of the work. One part of the beer brewing process is the *filtration process.* This process is where the flavor of the beer as well as the color is determined and stabilized. The addition of water and CO_2 is also part of this step in order to receive a high quality finished end product. During the filtration process the beer is measured on its percentage alcohol or the °Plato of the *original extract (stamwort)*. At *Grolsch*, an inline instrument from the company *Anton Paar* is responsible for measuring these values. The values are of importance in order to calculate the amount of water to be added to the process. This is necessary since beer is brewed more concentrated than the end product in an effort to produce more beer with minimum resources. Unfortunately, the instrument at *Grolsch* does not do its work sufficiently. At the moment, operators have to re-measure the values of alcohol and original extract manually to make sure the beer has the right composition. With the measurements, which they analyze in their laboratory, they can determine their following actions. The management team from *Grolsch* would now like to know why it is not possible to trust this and other inline instruments and why it is not possible to filter without human interaction. In the future they hope to have a more stable, efficient and trustworthy filtration process.

This first chapter consists of the research plan. Frist, an introduction of *Grolsch* and the filtration process (Section 1.1) that is followed by a more detailed description of the problem (Section 1.2). Finally, the problem statement and the research questions are explained (Section 1.3).

1.1. INTRODUCTION GROLSCH

The introduction of *Grolsch* starts with a short outline of the history of *Grolsch* (Section 1.1.1) and a brief description of *Grolsch*'s brewing process (Section 1.1.2) as well as an overview of the filtration process (Section 1.1.3).

1.1.1.HISTORY OF GROLSCH

Royal Grolsch N.V. is a Dutch brewery, part of the *SABMiller* group and located in Enschede, the Netherlands. The brewery was founded in 1615, in a small Dutch town called Grol (nowadays Groenlo), and since then the company has developed to a globally known beer brand. In 1876 the brewery had outgrown its demand and a second brewery was built outside of Grol. Years later, in 1895 the first brewery in Enschede was built. The brewery is especially famous for its swingtop bottle, the *beugel,* which was introduced in 1897. Bottles of this kind are equipped with a flip top cap, which makes it no longer necessary to open the bottle with an opener. In 1922 the brewery merged with another brewery, 'De Klok'. In the late 1950s the slogan 'Vakmanschap is Meesterschap' (Craftsmanship is Mastery) was introduced. This slogan became *Grolsch*'s motto and is based on the idea that the mastery of the craftsman is like beer brewing at *Grolsch*. In 1955 then, the brand was awarded the title "Koninklijk" (Royal). On May 13 in 2000 a fireworks factory in Enschede, only 200 meters away from the brewery, exploded and destroyed the whole district, therefore also the brewery. After a few difficult years of restoration, *Grolsch* continued to grow and since 2004 *Grolsch* beer is brewed in the new brewery between Enschede and Boekelo. Since February 2007 *Grolsch* can be enjoyed out of its new, green beer bottle. More than 400 years after the brewery was established, *Grolsch* is available in 70 countries worldwide and is the 21st largest beer provider.

1.1.2. BREWING PROCESS

Grolsch does not only brew their famous *Grolsch Premium Pils*, but also other beers like their *Radler* or special beers like the beers *Lentebok* and *Herfstbok*. Beer is brewed with the four basic ingredients water, malt, hop and yeast. Figure 1-1 shows the process of beer brewing. The first step of brewing beer is the actual brewing process where the malt is milled with water and heated up. Wort results from the mixture and the husks are separated from the liquid. After that the mixture is filled into the fermenter tank where yeast is added and alcohol as well as carbon dioxide arises. To separate the yeast from the substance, everything is treated through centrifuging. Then the mixture matures in the storage vessels and finally the beer is filtered. This is done to produce a clear uniform beer. Since the beer is brewed with a higher concentration, water and carbon dioxide are added to receive the right amount of alcohol and original extract. In the end, the beer is stored in the bright beer tank (BBT) from which it is then pumped into the filling lines. Here the beer is filled into cans, bottles or kegs and finally packed into boxes or crates. These are then kept in the warehouse before they are being delivered to their customers.

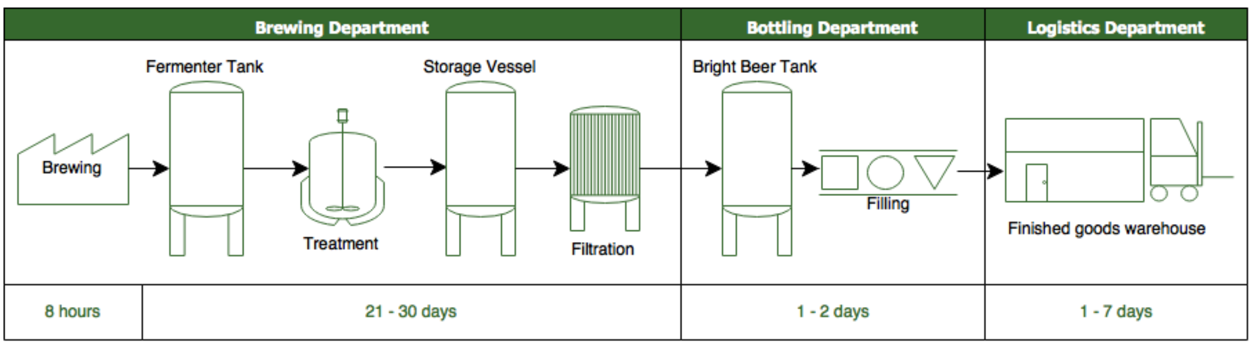

Figure 1-1 - Grolsch's Brewing Process

1.1.3. FILTRATION PROCESS

As described above, the filtration process is an important part of beer brewing. Responsible for the process of beer brewing and beer filtering within *Grolsch* is the *Brewing Department*. 36 people are employed here.

At *Grolsch*, beer is mechanically filtered by flowing the beer through the filtration line. Through filtration the beer is standardized and becomes clear. The filtration line is constructed with multiple filters and buffer tanks shown in Figure 1-2. The beer is filled from the storage vessel, where it has been stored for approximately ten days, into the unfiltered buffer tank (UBT). This is the start of the filtration. The first filter is the *Kieselguhr (KG) filter*. It is used to filter fine particles out of the beer. After the KG filter, the beer has to flow through the P*olyvinylpolypyrrolidone (PVPP) filter*. The PVPP filter filters the polyphenols out of the beer and thus clear beer with stable foam is produced. After the PVPP filter, the beer flows through the t*rap filter*. The trap filter is fine enough to remove almost all rest particles. Now the beer is pumped into the filtered buffer tank (FBT). After this, water is added to the beer. Inline instruments take continuous samples and the automation system calculates the values of water and CO_2 that need to be added. After filtering, the beer is held in the bright beer tanks until packaging.

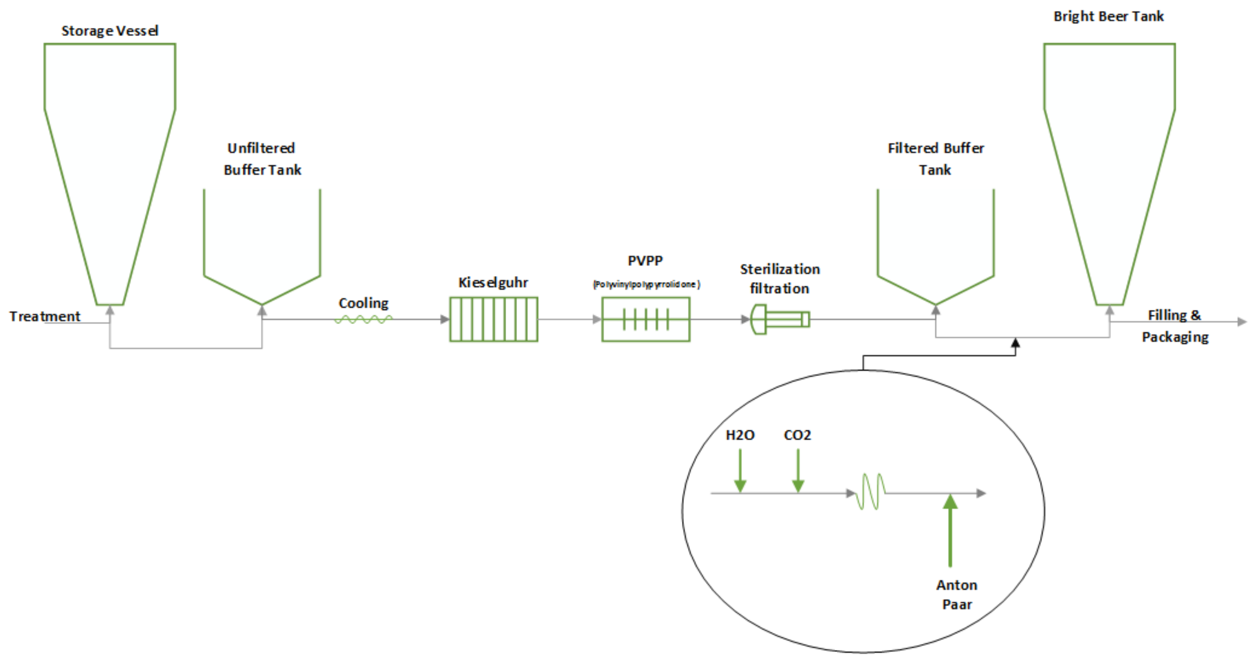

Figure 1-2 – Overview of Grolsch's Filtration Process

1.1.4. INLINE INSTRUMENTS

Figure 1-3 - Anton Paar Inline Instrument

After the actual filtration the beer flows through inline instruments. One of the instruments is used for continuous, real time monitoring of the alcohol content and original extract of alcoholic and non-alcoholic beverages. The instrument used at *Grolsch* is a combined density and sound velocity measurement instrument. Density and sound velocity are determined simultaneously before the data is processed. The instrument calculates the alcoholic strength and amount of original extract with the measurements. It can compensate for the CO_2 that is already in the beer, at the same time. Another instrument measures the CO_2 values. The instruments are of great importance for the legal foundation of the beer. Beers are brewed according to the percentage of alcohol or the °Plato of the original extract, the sugar which is in the wort. Exported beer must be brewed according to the percentage alcohol since it could otherwise not fulfill the export regulations since the deviation in alcoholic strength needs to fluctuate less than from domestic products.

1.2. PROBLEM DEFINITION

The management team of *Grolsch*'s Brewing Department wants an analysis of the filtration process and a plan of action. They want to find out why the inline instruments are not trustworthy and why the measurements are not accurate. To get a better understanding and to identify the action problem, a problem cluster is made.

A problem cluster is a method in which causes and effects of problems are logically linked and a clear action problem can be found (Heerkens, 2004). The main action problem has to be the cause of the other problems and not the consequence or the symptom of another problem. In order to arrange the problem cluster, the most relevant stakeholders are asked about their knowledge and assumptions. The primary stakeholders are the operators. These are the people who operate as well as supervise the brewing process. They also have to implement the final action plan. The analysts from the quality assurance, technicians and the managers of the Brewing Department are secondary stakeholders. All of them are involved active by the problem solving approach. The managers especially hope that this research will make the filtration process and the work of the operators more efficient. From these conversations new causes and its consequences become clear and the problem cluster can be made. The problem cluster is shown in Figure 1-4, followed by a brief description of the problems. A more detailed stakeholder analysis based on a method described by Reed et al. (2009) can be found in Appendix A.

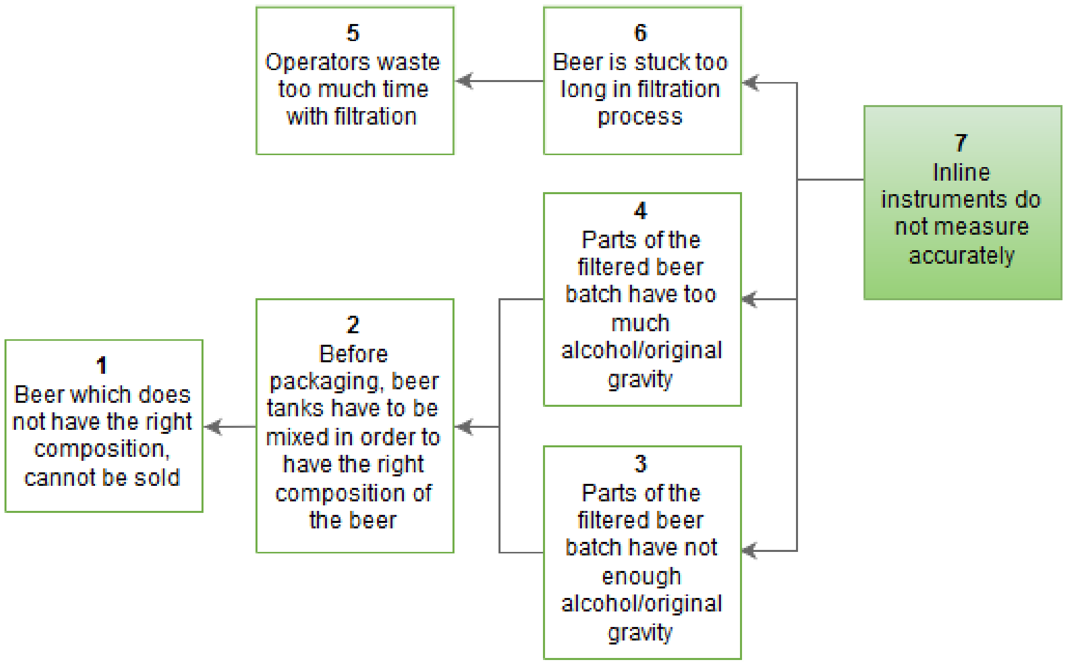

Figure 1-4 - Problem Cluster

1. If *Grolsch* brews export beer, the beer needs to have the right composition in order to be sold. The laws for export goods are stricter than the laws within the Netherlands.
2. Since the BBTs do not always store the right mixture of beer, the tanks have to be mixed. The causes of this action are often the inaccurate measurements. Since the measurements are inaccurate, the first and the second part of the beer need to be mixed in order to have a beer with the right concentration. This means that if the first part of the filtered beer consists of stronger beer, the second part of the beer needs to have less alcohol/original extract. In the end, the beer is in one tank. To mix the beer, CO_2 is added from the bottom. This way the beer circulates and is mixed.
   An example: Amsterdam Maximator, which is also brewed at *Grolsch*, has 12% alcohol by volume (abv). If the first part of the batch is brewed with 11% abv, the second part of the batch has to have more than 12% abv in order to get a beer with the right percentage of alcohol[1].
3. Since the measurements are not accurate, sometimes parts of the filtered beer batch do not have enough alcohol or original extract.
4. Since the measurements are not accurate, sometimes parts of the filtered beer batch have too much alcohol or original extract.

[1] Values are changed due to confidential information.

5. Operators often have to adjust the filtration process manually since they do not trust the inline instruments. Through taking samples they can figure out which adjustments they have to make. Since the operators have to make adjustments manually, they waste a lot of time on the filtration process. They should be using this time more efficiently.
6. Because the inline instruments do not measure accurately, the beer is stuck longer in the filtration process and the operators spend their time monitoring the process.

7. *The action problem as well as the starting problem of this research is that the inline instruments do not measure accurately.*

Further, visits at the company have shown that *Grolsch* tried to solve this problem through letting the operators take approximately every 500 hectoliter samples and letting them adjust the values within the automation system manually. This unfortunately does not solve the problem. On the one hand, operators are now constantly busy with these measurements, and on the other hand the manually adjusted values are not always correct either because the samples are not taken continuously or because there sometimes are human errors. With solving the primary action problem shown in Figure 1-4, the measurements will hopefully be more accurate and operators will not feel the need for constant re-measuring in the future .

1.2.1. RELEVANCE OF THE PROBLEM AND SCOPE OF THE PROJECT

By automating the brewing process within *Grolsch* the responsibility of brewing lies by the automation system. In the perfect situation, the system brews the beer automatically, only needing help from humans if there is an error or a problem within the process flow that it cannot handle on its own. Because of the inaccurate measurements of the inline instruments, the operators have to be cautious as soon as the filtration process begins. By taking measurements themselves, the operators can determine the adjustments they have to make within the automation system. The extra measurements have to be taken approximately once an hour and the manual process takes 20 minutes. This makes the filtration process less efficient and less stable. When operators are busy with other tasks, it could happen that a bright beer tank has a too high or too low alcoholic strength or the °Plato of the original extract is too high or low. If this happens, they have to change the recipe for the second part of the batch. This way they can brew the beer according to the target values. With a more stable, trustworthy and efficient filtration process, operators could pay more attention to other problems and processes. In the future this could mean that operators spend less time with the filtration process and that the beer can be packaged faster.

This problem troubles the efficiency end effectivity of the brewing process within *Grolsch*. The management team is curious what the causes and problems behind the inaccurate measurements of the inline instruments are and wants to create a more stable environment. The productivity of the operators as well as the system could be increased through decreasing the time spent for filtration.

The scope of this research is to analyze the filtration process and the possible causes for the inaccurate measurements of the inline instruments. It is important to find out why the instruments do not measure accurately in order to create a stable process flow. Since there is limited time for the research there are some research limitations. The plan is to give *Grolsch* an action plan at the end of this research. The implementation of this plan is not part of the assignment.

1.3. PROBLEM STATEMENT AND RESEARCH QUESTIONS

The main problem of *Grolsch*'s filtration process is not knowing why the inline instruments, especially those from *Anton Paar* are not measuring accurate values. The described problem leads to the following problem statement and action problem:

How can the inaccurate measurements of the inline instruments within Brewery Grolsch's filtration process be improved?

This research is limited to the filtration processes of *Grolsch* and has therefore no external validity. The objective of the research is to optimize the measurements of the inline instruments and to have a more efficient, trustworthy and stable process. The operationalization of the key variables and the target of values during the process are described in Section 1.3.1. To find possible causes for the described problem and ultimately a solution, the following research questions are answered.

1. *What is the current filtration process at Grolsch?*

To better understand the process, first the filtration process has to be analyzed. This question is a knowledge problem. Understanding the filtration process also means understanding the inline instruments and their function and role as well as importance in the process. This will be done through researching the particular instruments and talking to the instrument technicians. The *Brewmaxx* system is studied to get a better understanding of the automation system.

2. *What influences the filtration process?*

This question will be answered in three parts. It mainly covers the process of finding the possible causes for the action problem and is another knowledge problem.

i) *Which are the possible causes for the inaccurate measurements of the inline instruments?*

Grolsch has different ideas for the possible causes of the inaccurate measurements of the inline instruments, but of course there could be many more. Possible causes that *Grolsch* mentioned are:

- Bad maintenance of the instruments
- Wrong use of the instruments
- Wrong implementation of the instruments
- Wrong regulation within the automation system
- Ignorance / Distrust of operators
- Poor Process Control

To determine more possible causes, contact with the company *Anton Paar* has to be made. Additionally, employees from *Grolsch* have to be interviewed about their knowledge and experience. It will also be investigated if the employees think the causes, which are named above, could indeed be possible causes. The employees of *Grolsch* are the ones most familiar with the filtration process. By interviewing them through semi-structured interviews and holding group discussions, more possible causes can be identified. At the end of this qualitative research, a list with all possible causes will be made.

ii) *Which causes influence the filtration process most?*

Since the improvement of all possible causes cannot be tested, they need to be analyzed and categorized. The categorization will be based on the results of Methodological Triangulation. The method is used to check and establish validity in studies by analyzing the research question from multiple perspectives and insights (Guion, 2002). In the case of this research it will be done through different qualitative research methods and quantitative research, where possible. For this research, interviews and data collection as well as observations are used as research methods. With this method the consistency of the findings can be checked by using different data collection methods. Each of the multiple sources of data is able to give a different outcome and picture. Therefore, each data source is first considered and analyzed individually but in the end combined for a comprehensive view (Drouin, Stewart, & Van Gorder, 2015). This approach is necessary to know which possible causes are most likely the problem behind the inaccurate measurements. This method can also eliminate some possible causes. For more insight, the operators and laboratory workers are interviewed and an Ishikawa diagram is made during brainstorming sessions. This tool will make the causes and effects of the possible causes clear and visible. At the same time quantitative research will be done, if the data is available, to double-check the results gained by the qualitative research.

iii) *What are the causes behind the most severe problems identified in 2ii?*

After the possible problem causes are categorized, the possible causes need to be analyzed further. This analysis deals with solving the problems. With the help of the employees of the Brewing Department, the origin of the main problems is investigated. Here the problems that are determined most likely to be the possible cause are reviewed first.

3. *What should Grolsch do to improve the filtration process?*

In the end, conclusions are drawn and recommendations and an action plan for *Grolsch* is written. The conclusions are based on the findings of the previous questions. Furthermore, literature review is done for solving the causes of the severe problems that were found in 2 iii). The action plan also includes recommendations for future actions and research in order to prevent this problem from happening again.

1.3.1. OPERATIONALIZATION OF KEY VARIABLES

While filtrating the beer, the most important value of the filtration process is the °Plato of the original gravity or the alcoholic strength. Depending on the beer that is brewed, one of the two is measured continuously during the filtration process. At the moment, operators have to take samples and measure these values. Sometimes the values the operators measure are not the same as the values that the inline instrument measures. In that case they have to adjust the automation system manually. The third party that measures the values is the laboratory from the *Quality Control Department*. They take measurements of all beers and their measurements are seen as the most trustworthy.

The acceptable values of the beer are split into different categories. These values are decisive for the quality of the final product. The original extract in °Plato may approximately deviate 2-3 percent. The alcoholic strength on the other hand may deviate 2-6 percent. This differs depending on the product. The target value is the value that the system tries to reach. The lower and upper specification is the margin that has to be reached by the operators. The lower and upper limit alarms the operators to adjust the process in order to brew beer that is not rejected. The beer may under no circumstances reach the lower or upper absolute value. An example of this can be seen in Table 1-1.[2]

[2] Values are changed due to confidential information.

Table 1-1 – Quality Control Table

	Lower Absolute Limit	Lower Limit	Lower Specification Limit	Target	Upper Specification Limit	Upper Limit	Upper Absolute Limit
Original Extract in °Plato	11.74	11.78	11.82	12.0	12.18	12.22	12.27
% deviation Original Extract	2.2%	1.8%	1.5%		1.5%	1.8%	2.2%
Alcohol by volume in %	5.64	5.76	5.88	6	6.12	6.24	6.36
% deviation alcohol	6%	4%	2%		2%	4%	6%

The variables that have to be operationalized are the inaccurate measurements of the inline instruments. The key variables that will make the progress of this research measureable are thus the percentage of deviation in the measurements between the inline instruments and the quality control laboratory. The target deviation that is desired is one percent.

2. CURRENT SITUATION

This chapter extensively describes the filtration process at *Grolsch*. The description of the filtration process is necessary for the research of the possible causes. In Section 2.1 the filtration process with all filters and filter-aids is described. In Section 2.2 the use and the usefulness of the inline instruments is explained.

2.1. FILTRATION PROCESS

Beer filtration is an important part of the beer brewing process. It is done for different reasons. On the one hand beer is filtered for aesthetic reasons, people are conditioned to favor beer with a golden brown color over turbid beer (Lyke, 2012). On the other hand beer becomes transparent through filtration and proteins are removed (Lyke, 2012). This means that all acids, which are added to the process or which are in the beer, are removed and therefore the *shelf-life* of the product is increased (European Brewery Convention, European Brewery Convention Technology, Engineering Forum, & Coote, 1999). The shelf-life of products differs. While bottled products have a shelf-life of approximately 12 months, kegged products mainly have short term quality assurance.

There are a few particles that have to be removed from the beer before packaging. In addition to polyphenols, proteins and remains of yeast, beer contains metals and sugars, that make the beer turbid over time and under the influence of temperature (BASF, 2010). Most particles bigger than 5µm are removed throughout the process. The beer is analyzed at the end of the filtration run. The factors that are important for the analysis are: *Degree of clarity*, alcoholic strength, amount of original extract, amount of carbon dioxide (CO_2) and amount of oxygen (O_2). The basic physics behind the filtration process is Darcy's Law from 1856 (Buttrick, 2010) that emphasizes that the design of the filter has a big influence on the beer filtration.

Equation 2-1 - Darcy's Law for Beer Filtration (Buttrick, 2010)

$$\boldsymbol{Flow\ rate} = \frac{Permeability\ factor\ x\ Pressure\ drop\ x\ Area\ of\ filtration\ surface}{Filter\ bed\ thickness\ x\ Liquid\ viscosity}$$

$$\boldsymbol{Pressure\ drop\ across\ a\ filter\ bed} = \frac{Flow\ rate\ x\ Filter\ bed\ thickness\ x\ Liquid\ viscosity}{Permeability\ factor\ x\ Area\ of\ filtration\ surface}$$

Equation 2-1 shows the law of Darcy. The law describes what happens during the filtration process. The flow rate describes the rate with which the beer flows through the filter. This gives the brewery an idea of how long the filtration process takes. The *permeability factor* of a filter describes the pressure differential across the filter bed. This is laid down by the size and porosity of the filter-aid. The pressure drop is dependent on the filtration area of the filter. One of the easiest and cost effective ways to increase the capacity of filtration and therefore also the flow rate, is using a bigger filtration area. Through first centrifuging the beer after the actual brewing process, much of the solids, which are still in the mixture, are already separated from the beer. This increases the filtration performance. The filter run length is determined by the *sludge capacity*, the amount of filter-aid that can be put in a filter (Buttrick, 2007). The beer viscosity is improved in the last years through malt specifications that reduce beta glucans, a chain of glucose molecules, in the wort (Buttrick, 2010).

Filter aids are materials that are added to the filtration process for a better filtration quality. They form an incompressible mass that will then stuck to the filter medium and is further referred to as a filter cake

(European Brewery Convention et al., 1999). Within the process of d*epth-filtration* beer will flow into the filter cake and the finer particles are trapped there (European Brewery Convention et al., 1999). This way only clear beer flows forward through the process. With time and when more beer passes the filter, the filter cake fills the filter and therefore has to be removed and cleaned before the process can be restarted.

All the filters used in the filtration process at *Grolsch* are candle filters. Candle filters are vessels that encase a number of vertically mounted filter candles that are attached to a horizontal plate (European Brewery Convention et al., 1999). The candles are continuous spirals with comprised dimples, which provide spacing for the liquid flow. This type of filter can be seen in Figure 2-1.

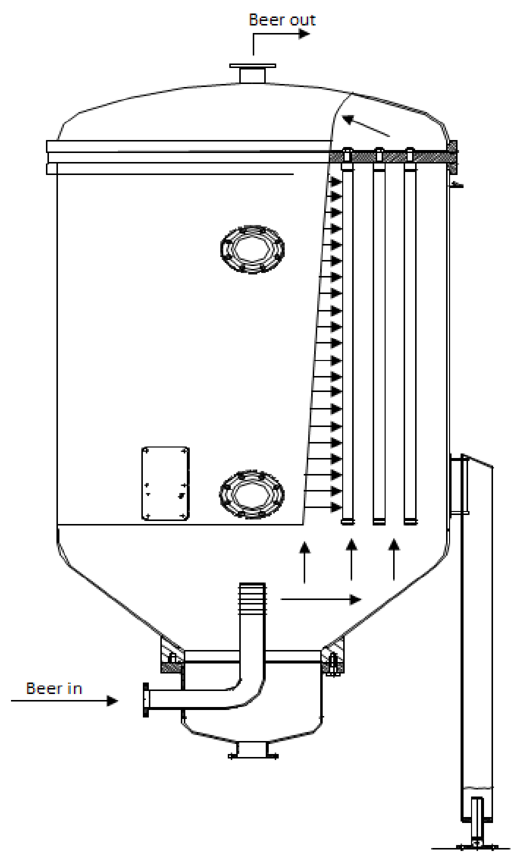

Figure 2-1 - Candle Filter

In Figure 2-2 the filtration process at *Grolsch* is depicted in more detail. A flow chart can also be found in Appendix B. *Grolsch* has three filtration lines. Line one has a lower capacity than line two and three. These are identical. In this thesis filter line two and three are described if not noted elsewhere. A table of the filter volumes can be found in Appendix C.

Beer is mechanically filtered by flowing the beer through the filtration line. The filtration line is constructed with multiple filters and buffer tanks. The beer flows from the storage vessel, where it has been sitting for approximately ten days, to the UBT. This is the start of the filtration.

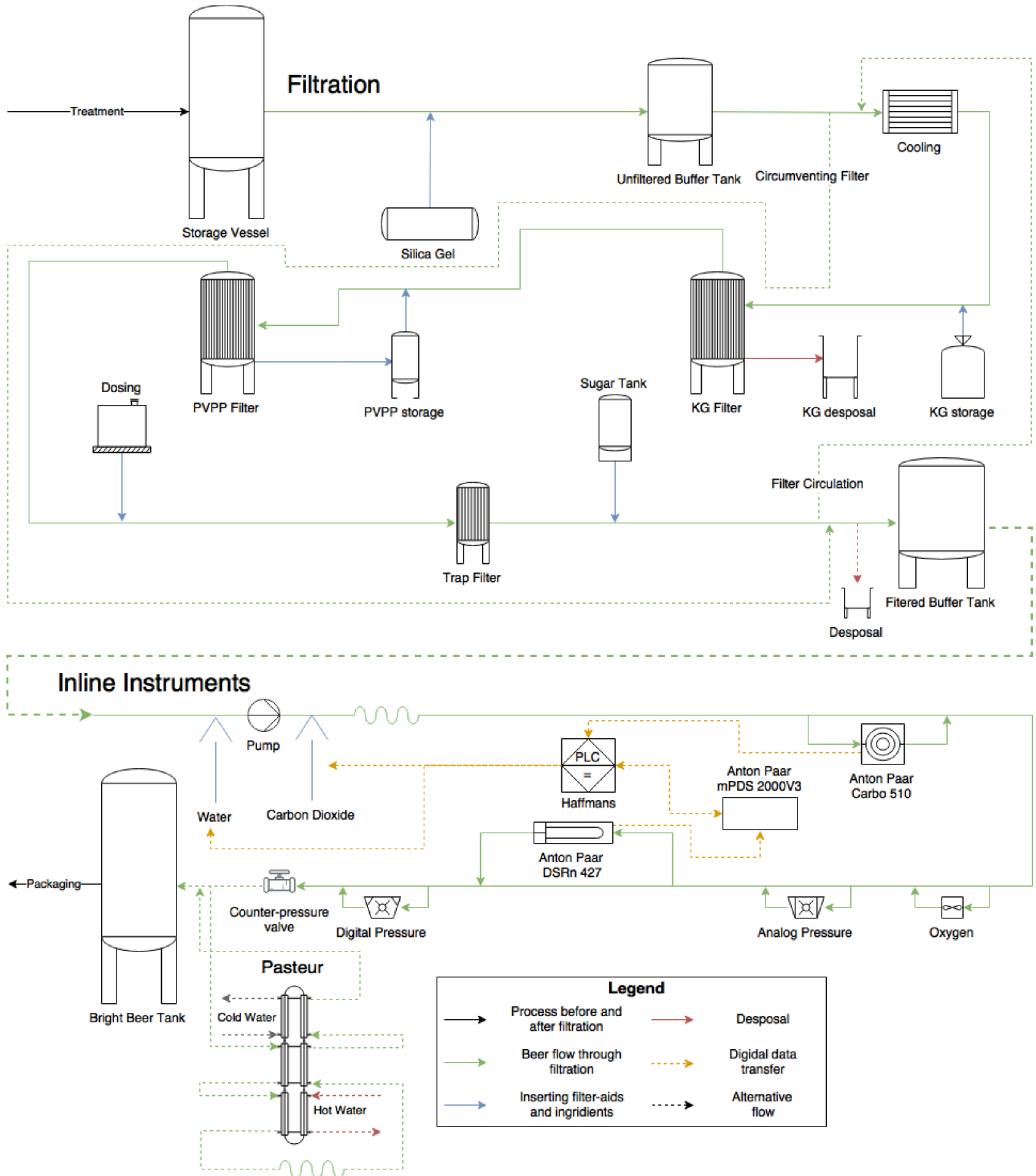

Figure 2-2 – Detailed Filtration Process at Grolsch

Before the beer arrives at the UBT, the filter-aid *Silica Gel* is added to the process. Silica Gel is a non-crystalline micro-porous solid powder, which is insoluble in water or beer (Rehmanji, Gopal, & Mola, 2005). It is tasteless, harmless for humans and is especially used since it does not trouble the foam forming process (Rehmanji, Mola, Narayanan, & Gopal, 2000). It has a high adsorptive capacity and is used for the removal of protein haze precursor reduction and improves the haze stability of the beer (Rehmanji et al., 2005).

After the UBT, the beer floats through a cooling system. Cooling reduces the time necessary to insure that all haze forming substances that could change the flavor and appearance of the beer in the finished product are filtered out, since the molecules in cool beer form a cluster that makes them easily filterable (European Brewery Convention et al., 1999). This way the removal of potential haze forming materials is maximized and the shelf-life of the product is prolonged.

The next step is the Kieselguhr (KG) filter. *Kieselguhr* is a product made from diatomite rock *or diatomaceous earth*, composed of the remains of single cell algae (European Brewery Convention et al., 1999). It is used to filter fine particles that would otherwise pass through and is especially designed for yeast particles. Water and kieselguhr are fed into the bottom of the filter vessel. The filter-aid then forms a cake on the outside of the candles. This process can be seen in Figure 2-3. At *Grolsch*, two different pre-coats of kieselguhr are used as filter-aid within the KG filter. The first pre-coat consists of rough particles and acts as a support for the second pre-coat. When the first pre-coat has surrounded the candle filters, the second pre-coat with bigger particles is inserted into the process (Figure 2-4). This way, unwanted particles are removed from the dull beer. The clear beer then flows evenly distributed into the vessel and into the filter candles. At the top of the vessel, the beer is transferred in the direction of the process flow. At the end of the filtration run, water is used to displace the remaining beer out of the filter. Once all beer is out of the vessel, the process flow within the KG filter is reversed and air is pumped into the vessel. This way, the cake is discharged and pumped into the disposal tank. This process cleans the filter at the same time.

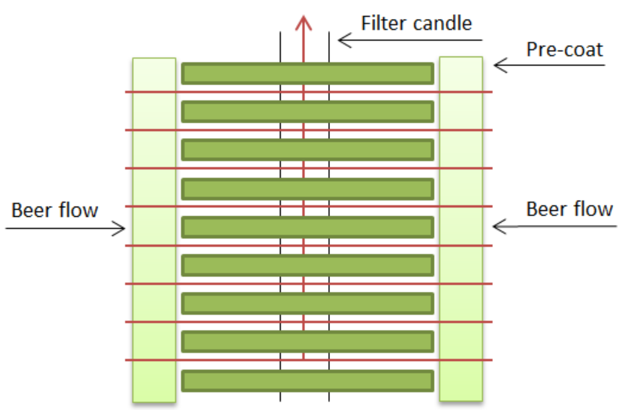

Figure 2-3 - Beer Flow through a Filter Candle

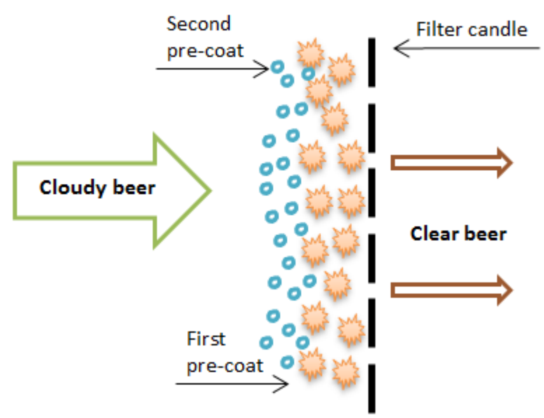

Figure 2-4 - Beer Flow through the Pre-Coats

Further, the beer is filtered in the Polyvinylpolypyrrolidone (PVPP) filter. PVPP is often used as a fining to extract impurities (European Brewery Convention et al., 1999). During the beer brewing process it is used to remove polyphenols and thus clear beer with stable foam is produced. The filter is constructed like the KG filter. The biggest difference is that the polyvinylpolypyrrolidone can be used more than once. Other than the kieselguhr, which is pumped into the disposal tank, the PVPP filter is first, like the KG filter, cleaned with water. After that, the filter is cleaned with acid before the PVPP is pumped back into its own tank.

The last filter in the filtration process is the trap filter. The trap filter is designed to filter out all smaller rest particles, which were not filtered out earlier. The depth filter cartridges are made from wrapped polypropylene filter material that is layered from coarse to fine. The filter material has a broad chemical compatibility and the polypropylene cage and core ensure maximum mechanical stability. The filters have a retention rating from 3µm. The filter candles have to be replaced regularly depending on their usage and the hectoliters they filtered.

2.2. INLINE INSTRUMENTS

Within the filtration process from *Grolsch* different instruments are used that ensure the quality of the beer. The most important instruments used for measurements, calculations and process control are:

- The *Anton Paar* DSRn 427 Density/Sound Velocity Transducer
  - combines density and sound velocity measurement in a single compact instrument (*Anton Paar*, 2010).
- The *Anton Paar* Carbo 510 Smart Sensor
  - CO_2 analyzers which combines the benefits of the inline measurement with the well proven pressure-temperature-impeller method (*Anton Paar*, 2013).
- Haffmans Carbo-Blender
  - type AGM, for automatic CO_2 determination with carbonator dosing device(Haffmans, n.d.).
- The *Anton Paar* mPDS 2000V3 Evaluation Unit
  - processor and display unit, designed for the continuous density and concentration measurement in industrial processes (*Anton Paar*, 2015).

The instruments are located after the filter and they are often referred to as *Beer Monitor*. They determine the original extract as well as the alcohol content of the beer in order to control the blending process. This means that with the measurements taken, the operators can determine the amount of water, which needs to be added to the process. The main player of these instruments is the Haffmans' operation panel. This device is connected to the automation system and can send alerts and errors to the operators.

During the production of beer, different values are important. On the one hand the alcoholic strength of the beverages, thus the percentage of alcohol is of importance. But not every beer is measured according to its alcoholic strength. Beers are either brewed due to the alcoholic strength, or due to a certain amount of original extract (stamwort). The original extract is the extract content of the beer before fermentation, thus an expression of the sugar content (Oliver & Colicchio, 2011). Specifically, it is the amount of sugar in grams per 100-gram wort. It is a theoretical value based on empirical studies, the Balling formula, and is used to recalculate the original extract content from the alcohol and real extract content of the fermented beer (Nielson, Kristiansen, Krieger Larsen, & Erikstrom, 2007). The most important equations are summarized in Equation 2-2.

Equation 2-2 - Equations for Determining Important Beer Filtration Parameters (Nielson et al., 2007)

The most important process during beer brewing is the fermentation process. Beer fermentation is a biological process in which fermentable sugars like glucose, fructose, maltose and sucrose are converted into cellular energy and during this process ethanol and carbon dioxide is produced. Original extract is the amount of sugar in the beer before fermentation:

$$Wort\ extract \rightarrow Alcohol + Real\ extract^{3} + CO_2 + New\ yeast$$

The original extract can be calculated through the strength of the wort:

$$Original\ extract\ (\%) = (Weight\ of\ extract\ in\ cold\ wort)/(Total\ weight\ of\ cold\ wort) * 100$$

Based on this, Balling thought of his famous formula, which shows the relations between the original extract to the real extract and alcohol:

$$Original\ extract\ (\%) = \frac{(2.0665 * alcohol\ by\ weight\ (\%\ of\ total\ mass) + real\ extract\ (\%\ Plato))}{(100 + (1.0665 * alcohol\ by\ weight\ (\%of\ total\ mass))} * 100$$

2.2.1. DENSITY AND SOUND VELOCITY TRANSDUCER

Besides the alcoholic strength and original extract, water and CO_2 are also of importance during the brewing of beer. In order to determine the concentration of all the components of a beer, the DSRn 427 combines density, sound velocity, temperature and CO_2 measurements into an optimum process measurement of alcohol content, original extract and CO_2. It is used to determine three concentrations in a three-component mixture.

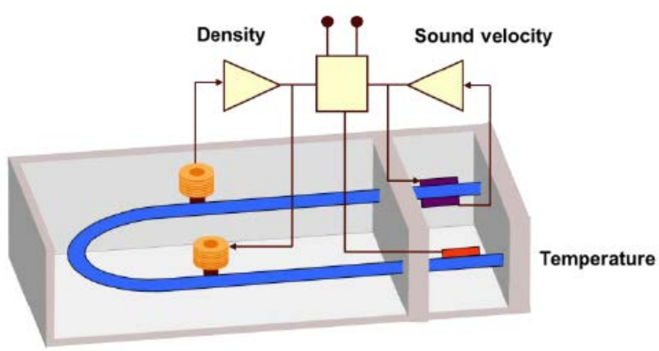

Figure 2-5 - Density and Sound Velocity Sensor (DSRn 427) (Anton Paar, n.d.-a)

The sensor consists of a U-tube density sensor as well as an integrated sound velocity sensor and is shown in Figure 2-5. The density of a material is defined as its mass divided by the volume. With the DSRn transducer, the density measurement is based on measuring the period of oscillation of a mechanical oscillator operated at its natural frequency, precisely according to the oscillating U-tube principle (*Anton Paar*, n.d.-a). The density of beer is determined through measuring the periodic time of the flexural

[3] Real extract are the sugars remaining in the finished beer.

vibration (Bismark, 2008). By means of a magneto-electrical excitation system, the U-tube is excited to a continuous oscillation at its natural frequency. The frequency is directly related to the density of the beer, which is flowing through the U-tube. At the same time sound velocity is measured over a fixed distance by an ultrasonic transmitter as well as receiver, located on one side of the U-tube (*Anton Paar*, n.d.-a). The velocity of propagation is determined with a repeatability of 0.01 m/s. The electronics in the U-tube measure the propagation time of ultrasonic pulses through the beer and calculate the sound velocity. Both density and sound velocity are dependent on the temperature of the beer. Therefore, the temperature has to be measured highly accurately in the U-tube and needs to be integrated in the calculations of density and sound velocity.

In Figure 2-6 the relationship between alcoholic strength and sound velocity can be seen. With increasing strength of alcohol, the density decreases, but the sound velocity of the beer increases. In Figure 2-7 the relationship between sugar and density as well as sound velocity is described. With increasing extract, the density and sound velocity increase, too. Since the extract from beer is not a pure sugar solution but a mixture of various components, the graph of extract and sugar are not identical.

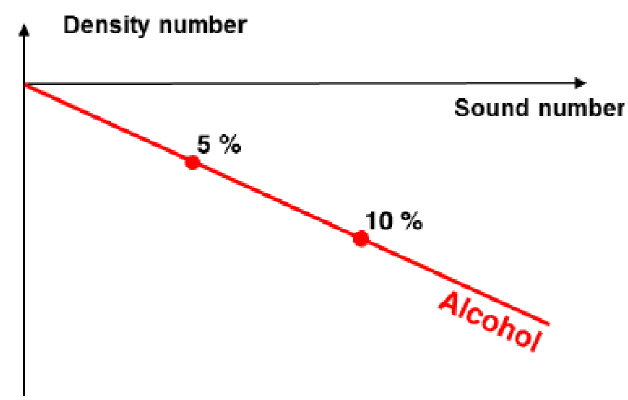

Figure 2-6 - Relationship: Alcohol and Sound Velocity (Anton Paar, n.d.-a)

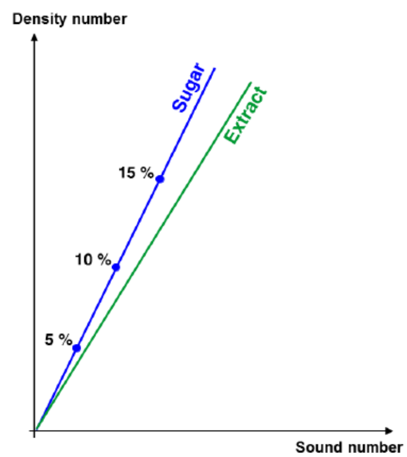

Figure 2-7 - Relationship: Sugar, Density and Sound Velocity (Anton Paar, n.d.-a)

2.2.2. CO_2 SMART SENSOR

Also CO_2 is of importance during the measurement of original extract and alcoholic strength. The Carbo 510 Smart Sensor measures and analysis according to Henry's law (*Anton Paar*, 2013). This law defines the relationship between the concentration of the dissolved CO_2 and its saturation pressure according to the temperature of the beer. The method that the *Anton Paar* instrument uses is called 'Volume Expansion Method'. The method is based on the fact that the solubility of CO_2 is much higher in beer than in air. The process can be seen in Figure 2-8. The beer is flowing through the measuring chamber and fills the whole chamber. The impeller accelerates the flowrate of this process (Number 1). Next the valves are closed and the chamber is sealed tightly (Number 2). Then, the chamber is expanded and the impeller starts rotating (Number 3). Since the volume of the chamber expands, a vacuum is created. The rapid rotation allows for rapid pressure and temperature equilibrium. Knowing that the partial pressure of air decreases more than the partial pressure of CO_2, the exact CO_2 value is measured. In the end, the chamber opens again and the beer is replaced. The Carbo 510 measures the CO_2 content of the beer every 15 seconds.

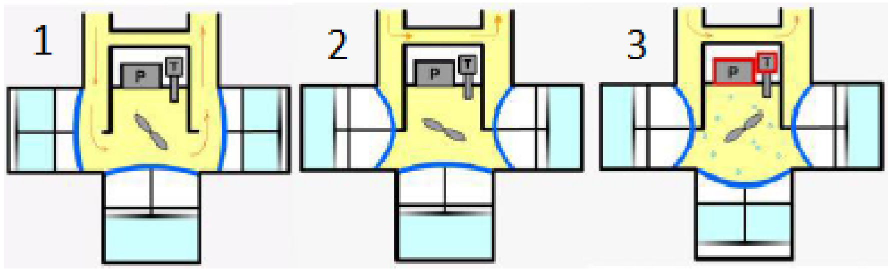

Figure 2-8 - Measurement of CO_2 Smart Sensor (Anton Paar, n.d.-a)

The CO_2 content is calculated from the saturation pressure as well as the temperature, measured in the chamber. The relationship between CO_2 content and saturation pressure depends on the composition of the beer as it can be seen in Figure 2-11. The CO_2 content after the filtration and the CO_2 content in the bottle or keg may vary due to loss of CO_2 after filling or before closing the bottle or because of additional carbonization in the buffer tank.

2.2.3. HAFFMANS CARBO-BLENDER

Haffmans instrument is a carbo-blender and is used for the carbonation of the beer. It can dose the feeding of CO_2. The goal of carbonation is to dissolve the added CO_2 as quickly and completely as possible (Haffmans, n.d.). This means that no free CO_2 bubbles can be seen in the beer. The dissolving of the CO_2 can be visually checked through an inspection glass in the outlet of the dissolving tube.

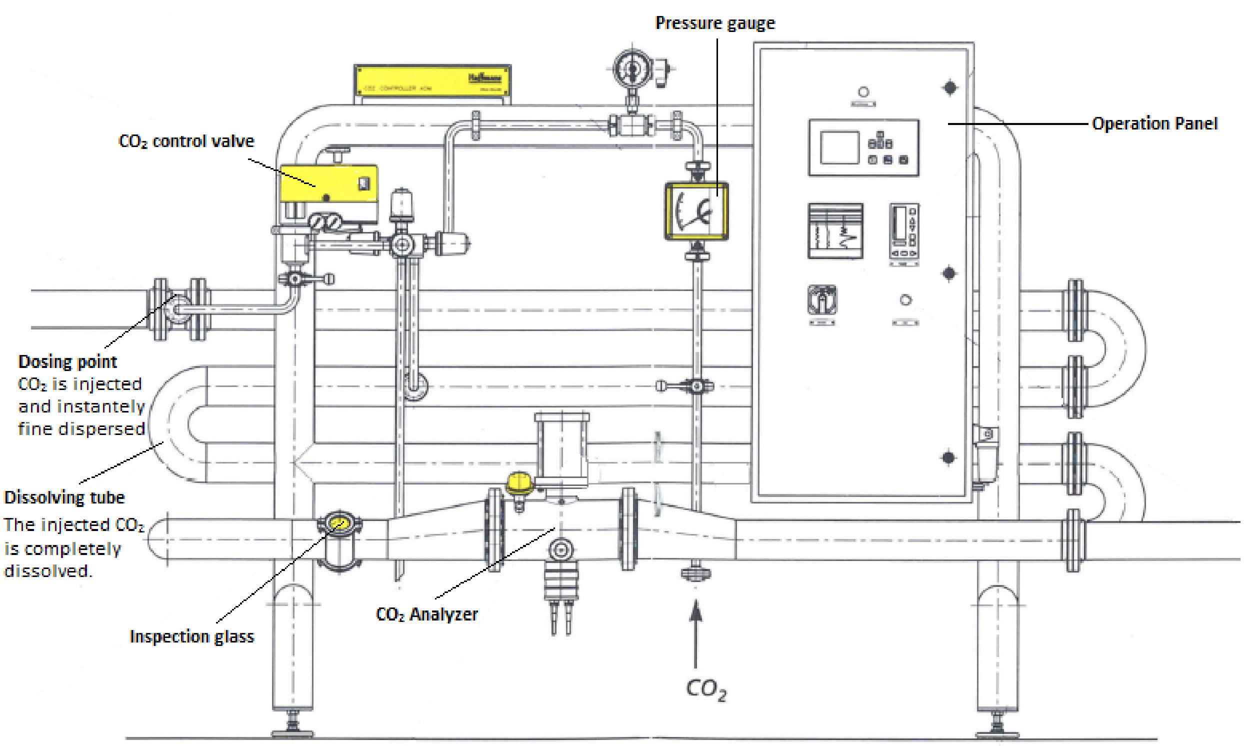

Figure 2-9 - CO_2 Dosing Device

The instruments consist of different parts, which can be seen in Figure 2-9. The CO_2 analyzer is not installed at *Grolsch*. Instead of the analyzer, the Carbo 510 measures the CO_2-content and communicates this value with the Operation Panel. Within the Operation Panel, there is also a programmable logic controller (PLC). It is a digital computer used for automation of the filtration process. It controls instruments, valves and stores important set-points. The recipes for the beers are also stored here. The PLC also monitors the blending of water and feeding of CO_2. The Carbo 510 gives its measurements to the PLC. The measurements are then used to inject the right amount of CO_2 into the main beer line. In the inlet of the dissolving tube CO_2 is injected and fine dispersed with several mixers. In addition, it sends the CO_2-values to the mPDS. The mPDS sends the PLC in return the alcoholic strength and calculated original extract. With these values the PLC can calculate the water that needs to be added. The advantages of the beer analysis after the filtration are that the original extract measurement requires a known CO_2 concentration and is therefore to be installed directly after the CO_2 Doing Device.

2.2.4. EVALUATION UNIT

The Evaluation Unit is a powerful processor and display unit, designed for the continuous density and concentration measurement in the beer filtration process. Next to the calculation of the basic properties within beer filtration, specific parameters can be stored for temperature compensation, concentration determination, alarm limit monitoring and adjustment of measuring values. This measurement is useful for continuous beer quality monitoring. How the Evaluation Unit and the inline instruments are installed in the process flow can be seen in Figure 2-10.

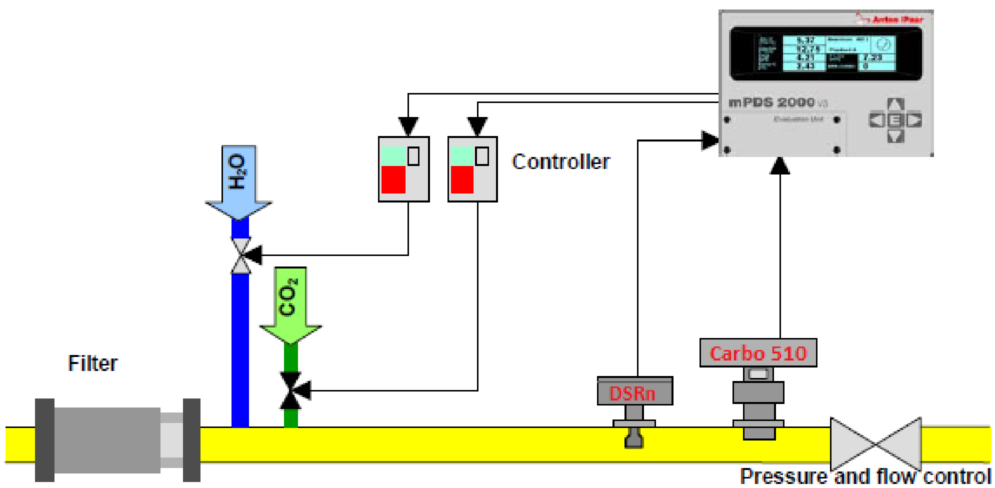

Figure 2-10 - Installation of the Beer Monitor (Anton Paar, n.d.-b)

When DSRn 427 and Carbo 510 are inserted into the beer line, the measurements of the two instruments can be transferred to the Evaluation Unit by wired cables. The calculations of the alcoholic content and the original extract can be made more accurate since the values from Carbo 510 can be used to compensate for the CO_2 content. Without Carbo 510 the calculations can be made as well, but then an estimate is used for the CO_2 content.

The Beer monitor processes the relationships shown in Figure 2-6 and Figure 2-7. Combining these graphs leads to a coordinate system as it can be seen in Figure 2-11. The combinations of the alcohol, extract and water values span a vector space referred to as plane. The Beer Monitor processes the data using sophisticated polynomial formulas and automatically calculates the values of alcohol and original extract from density, sound velocity, temperature as well as CO_2.

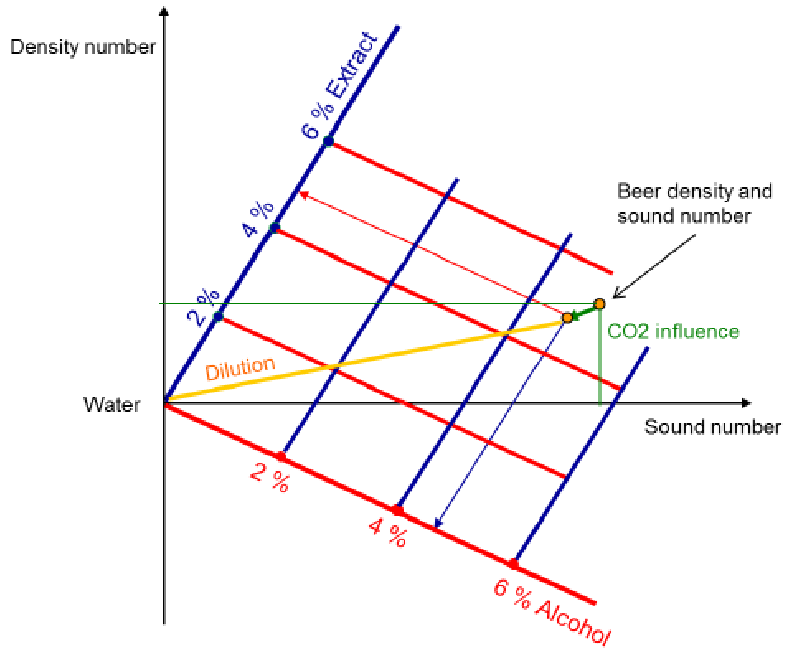

Figure 2-11 - Measuring Alcohol and Extract by Sound Velocity and Density (Anton Paar, n.d.-a)

2.3. CONCLUSION

The current filtration process at *Grolsch* can be divided into two main processes. The first process is the filtration where the particles are removed from the beer. Though this research especially focusses on the second process, the measuring and blending process. Measuring and blending is important in order to produce beer according to the recipe. This chapter gives answer to the first research question: "What is the current filtration process at *Grolsch*?" The description of this chapter gives a clear insight into the current situation. This is a necessary starting point for researching possible causes for the inaccurate measurements of the inline instruments.

3. INFLUENCES ON THE FILTRATION PROCESS

This chapter identifies and describes the possible causes for the inaccurate measurements of the inline instruments (Section 3.1). Further, it analyzes their influence on the filtration process and categorizes them (Section 3.2) and finally it presents conclusions on the origin and impact of the influencing factors (Section 3.3).

3.1. POSSIBLE CAUSES FOR THE INACCURATE MEASUREMENTS

Identifying the possible causes of the inaccurate inline measurements is the main objective of this research. The possible causes, which are being identified in this chapter, are ideas of stakeholders and do not necessarily all need to be relevant for this thesis. The operators, laboratory workers and employees of the companies that produce and install the inline instruments, are the most relevant stakeholders and involved in this step of the research.

3.1.1.CAUSE AND EFFECT OF THE POSSIBLE CAUSES

Since it is challenging to find out root causes for the inaccurate measurements, an *Ishikawa Diagram* is used as a helping tool. The Ishikawa diagram in Figure 3-1 represents the possible causes and their effects for *Grolsch*'s current problem. The main problem at *Grolsch* can be identified as the inaccurate inline measurements during the filtration process. Ishikawa diagrams help to structure one's thoughts about possible causes and the reasons behind them (Sondermann, 1994). In the end, they lead to a cause and effect diagram and help to identify potential factors causing the overall effect. The diagram for Grolsch is sketched to show the main and side causes of the problem identified above.

The diagram is made with the help of the employees from the Brewing Department. First, individual interviews are held with the operators. Here they identify problems. Then, the problems are summarized and plotted in the Ishikawa diagram. Next, a workshop is held with the manager of the Brewing Department and a few of the operators. Here the Ishikawa diagram is shown. At the meeting the problems are specified and some new problems are added.

In the Ishikawa diagram in Figure 3-1 *machinery*, *methods*, *manpower*, *material*, *measurements* and *management* are categories that contribute to and have an influence on the main problem. For each of the categories causes and sub-causes are found. The category *machinery* addresses all issues with the filters as well as inline instruments that evaluate the process and control the blending. The causes listed under *manpower* mainly deal with the operators and their behaviors, attitudes, as well as work style. Under *materials* all possible causes are added that focus on the ingredients that are needed for brewing beer and the quality of the beer that arrives at the filtration process. The category *methods* include all methods that the workforce uses, for example maintenance and calibration. In the category *measurements* all causes that involve the values and measurements, taken during the process, as well as the factors that influence them, are listed. Finally, the category *management* includes possible causes that are based on the coordination and structure of the filtration process.

All possible causes and effects, which are found with the Ishikawa diagram during brainstorming, are combined into logical possible causes. These are listed as well as described in the next section. The analysis of the possible causes as well as a categorization, where some of the causes are eliminated, follows in Section 3.2.

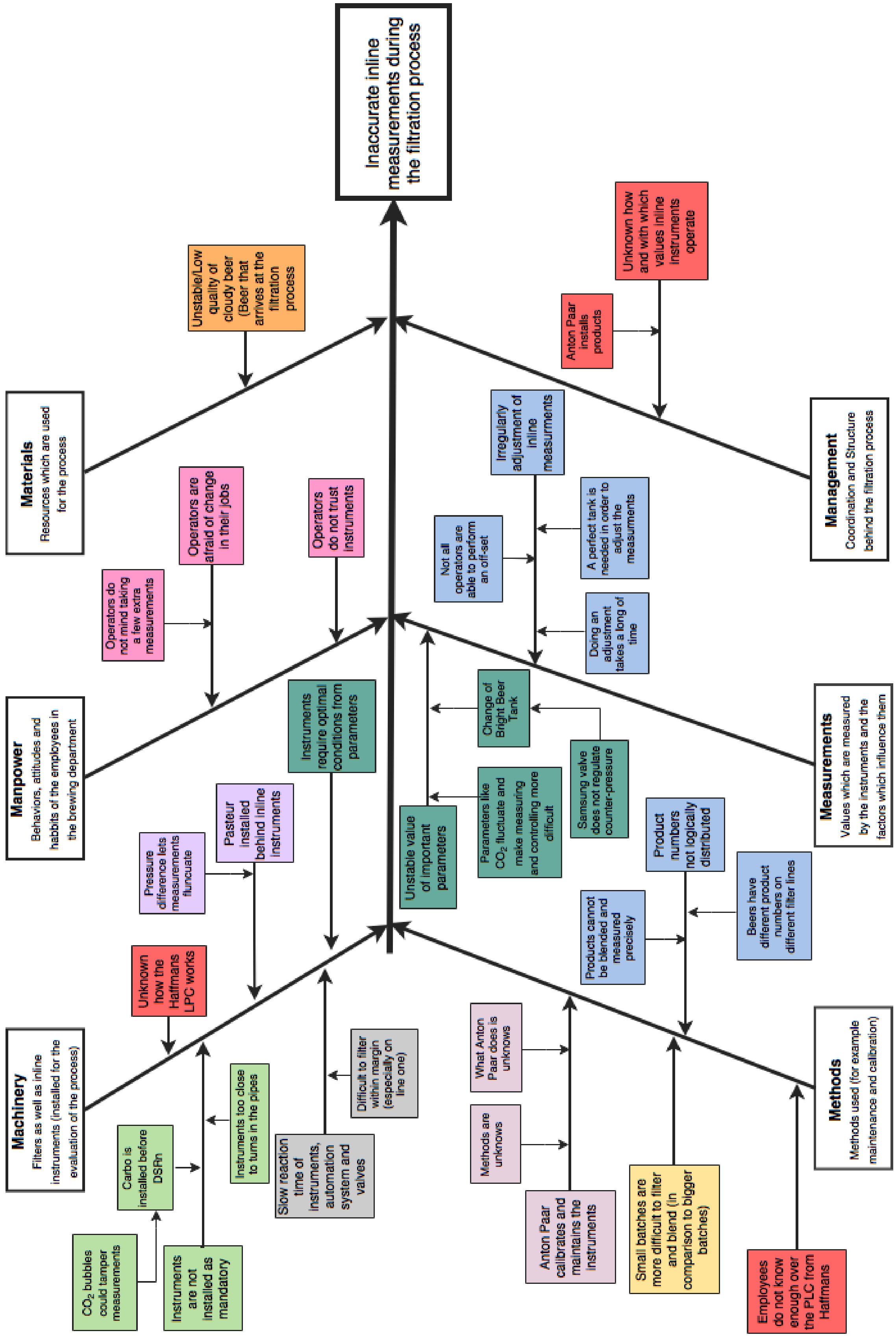

Figure 3-1 - Ishikawa Diagram

3.1.2. DESCRIPTION OF THE POSSIBLE CAUSES

During the previous research step some possible causes for the inaccurate measurements became apparent. The causes are researched by talking to the stakeholders as well as observing the process flow. The possible causes, which are shown in the Ishikawa diagram, are now combined logically with problem statements. The combination is possible by incorporating causes that belong to the topic and visualized by the colors. All possible causes for the inaccurate measurements at *Grolsch* can be seen in Table 3-1. Every problem will be further analyzed except problems concerning human commitment. This research focusses solely on the technical aspects, because they are most relevant.

Table 3-1 - Possible Causes for the Inaccurate Measurements

Possible Causes		**Further referred to as:**
1	Bad maintenance and calibration of the inline instruments	Maintenance and Calibration
2	Incorrect use of product numbers and wrong or irregular off-set of the instruments	Product-Specific Adjustment
3	Wrong installation of instruments in the filter line	Instrument Installation
4	Wrong regulation within the automation system	Regulation
5	Pressure difference through pasteurizing	Pressure Difference
6	Long reaction time from the automation system and valves	Reaction Time
7	Unstable value of important parameters	Important Parameters
8	At times the batches are too small	Batch Sizes
9	Brewing process provides unstable beer	Unstable Lager Beer
10	Human commitment	

This is the first step of the Methodological Triangulation. In this research the method is implemented as follows. Methodological Triangulation uses various methods and insights in order to check the results of one and the same subject. In this section the first phase of the process starts with the initial data gathering. The data gathering is based foremost on qualitative research. In particular, interviews and group discussions are held. The interviews are primarily held with operators, because they have the best insights into the process. In Section 3.2 the next phase of Methodological Triangulation is described.

1 - Maintenance and Calibration

Once a year, maintenance work needs to be carried out on the inline instruments. This means that the whole system has to be cleaned. Heavily worn and defect parts are replaced. This includes the diaphragms and O-rings, which need to be replaced every year. The employees do not know if this maitenance work happens according to the regulations. From Grolsch, there is no person who takes responsibility in this matter. They also don't know who the contact person from *Anton Paar* is.

2 - Product-Specific Adjustment

The mPDS Evaluation Unit can save the target values and warning limits of up to 256 products. A *Product-Specific Adjustment* helps to obtain more accurate results. At *Grolsch* and throughout the rest of this thesis the product numbers are referred to as the *Haffmans numbers.* The product-specific adjustment is a process that brings a measuring instrument into a state of performance, suitable for its purpose. It means minimizing the measurement errors as well as deviations by adjusting the measuring instrument. Any adjustment requires a more accurate reference instrument or reference standard. The results obtained from process measurement and laboratory analysis at *Grolsch* can show small deviations. This is why at

Grolsch the inline instruments are adjusted according to labratory reference values. Since the laboratory instruments are more often calibrated, the employees assume that these values are more accurate. The reasons for deviations are especially the different measuring methods used in the laboratory and process as well as fluctuating process conditions. A product-specific adjustment is done while the line is in normal operation. The mPDS Evaluation Unit is reset according to the off-set and gain factor. This is shown in Figure 3-2. The product-specific adjustment is product number specific.

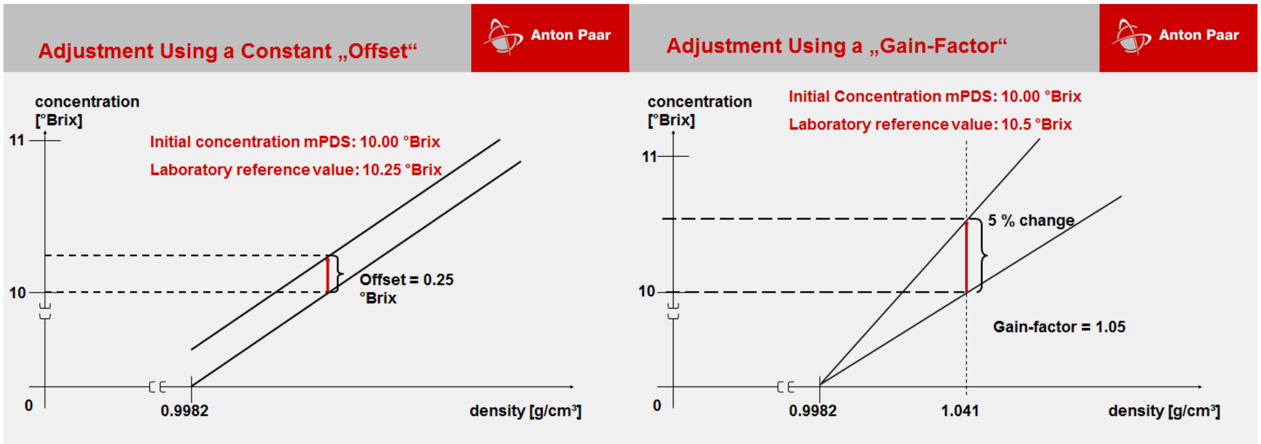

Figure 3-2 - Offset and Gain-Factor (Anton Paar, n.d.-a)

3 - Instrument Installation

The installation of all inline instruments is described in the instruction manuals. There are a few things that have to be considered. On the one hand, the device has to be away from a turn. This is shown in Figure 3-3. After a turn, turbulences arise within the beer. If during this, measurements are taken the instruments will be exposed to rapid variation of pressure and flow velocity. This is why measurements can be imprecise.

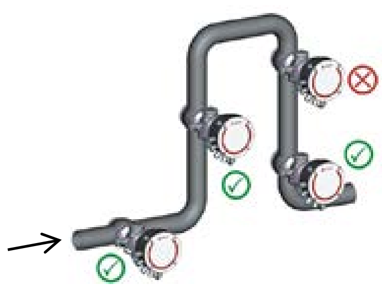

Figure 3-3 - Distance from a Turn (Anton Paar, 2013)

On the other hand, the instruments should be installed in a certain order. According to the instruction manual, the Carbo 510 has to be installed after the DSRn 427. At *Grolsch* this is done the other way around due to lower expenses and ease of installation. The reason why the instruments should be installed the other way around is the risk of CO_2 bubbles within the U-tube of the DSRn 427 instrument. The Carbo 510 extracts the CO_2, which is in the beer, from the beer. After the measurements the CO_2 is brought back into the process flow. Through bringing it back, a pulsating current as well as CO_2 bubbles arise in the process flow and these can falsify the measurements.

4 - Regulation

The measurements from the inline instruments are used within the automation system. They are of value for calculating the amount of water and CO_2 that needs to be added. It is important that the right measurements are used for these calculations. At *Grolsch* it is not clear if the values are taken from the right measurements. Employees speculate that there could be inconsistencies or wrong connections.

5 - Pressure Difference

Pasteurization is a process that reduces the amount of bacteria in beer and other liquids through heating the liquid. Some products at *Grolsch*, like the Weizen, are not filtered but pasteurized. It therefore circumvents the filterstreet and only passes the last part of the line with the inline instruments. As with the other beers, the inline instruments calculate the alcoholic strength and the original extract to add the necessary amount of water and CO_2. After blending, the beer flows to the pasteur. The big problem with the pasteur is the pressure that is needed for this process. While the inline instruments need a pressure of five bar to dissolve the CO_2 in the beer, a pressure of twelve bar is needed during the pasteurization. If the pressure during pasteurization is higher or lower than the set-point, the beer flows too fast or slow through the process and not all or too many bacteria are killed. In order for the quality of the beer to be acceptable, the pump installed in the pasteurizing process, sets the pace. This means that the inline instruments do not work within their required operating range. If the pressure in the pipe is outside of this range, the operating accuracy is lower which means that greater deviations and greater total error are to be expected. For beers that are pasteurized, this means that the measurements of alcoholic strength and original extract are less accurate than for not pasteurized beers. This can be seen in Figure 3-4. The figure shows the probabilty distrubution of Weizen, a pasteurized products, and Pils, a filtered product.

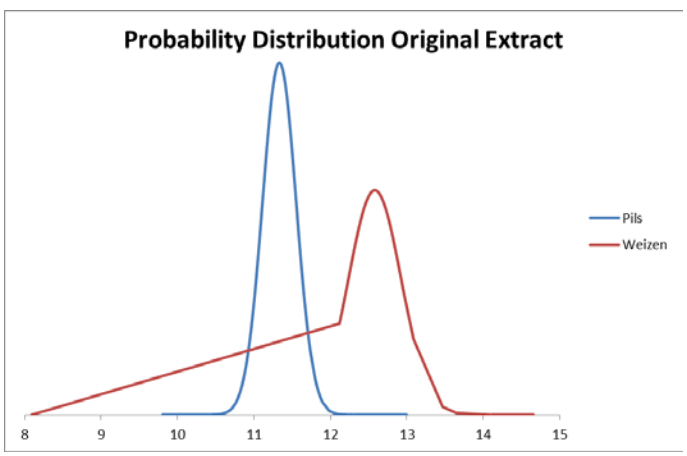

Figure 3-4 - Difference in Standard Deviation - Weizen and Pils

6 - Reaction Time

During the filtration process, water and CO_2, amongst others, are added to the process. The feeding and blending depends on the values of the inline instrument measurements in the passing beer. Sometimes, during the process the values have to be changed manually in the automation system. The values mainly have to be changed because of the difference in the inline and laboratory measurements. Described below is an example for changes that have to be done.

If the recipe says that a beer needs to have an alcoholic strength of 7%, the inline instruments are set accordingly. After some time, the operator takes a sample of the beer and notices that the alcoholic strength is not at 7%, but at 9%. Since the passing beer has an alcoholic strength that is too high, more water needs to be added in order to have the right alcoholic strength in the end product. The operator has to change the values in the automation system manually. The opposite has to be done if the alcoholic strength is too low. Other values that have the same influence on the process are the original extract and CO_2. If the values of the measurements are too low or too high the values have to be adjusted. Here, the main problem is that the operators noticed that the valves need a long time to react to changing conditions. They indicate that it occasionally takes some time for the flow of the blending and feeding devices to adjust to the values that were manually adjusted.

7 – Important Parameters

For the filtration process a lot of parameters are of importance. A distinction has to be made between process condition parameters and sample beer parameters. Process condition parameters are as the name implies, parameters that describe the condition of the process. Examples are pressure, flow speed or temperature. Sample beer parameters, on the other hand, are the parameters that are important for the final product. They control the target values of the recipe and are the deciding factor for blending. Important sample beer parameters are original gravity, alcoholic strength as well as the CO_2 content of the beer. For each instrument and recipe, the target values are different. Unfortunately, some values are often fluctuating. An example for this is the temperature of the unfiltered beer. Before the actual filtration process begins, the beer needs to be cooled to zero degrees. But sometimes the beer in the storage vessel is already cooler than zero degrees. If this beer arrives at the filters, it cannot be filtered consistently since ice-crystals are clogging the filters. Because not all holes can be clogged, some of the beer still passes the filter. The values that the inline instruments measure of this passing beer, are not accurate since the beer is too cold.

8 – Batch Sizes

The operators also named small batch sizes as a part of the problem with the inaccurate measurements. In the beginning of the filtration process, the values of original extract and alcohol still fluctuate. This happens because the beer on the bottom of the vessel is mixed with water. Since the storage vessels are pumped empty from the bottom, the same liquid also flows first through the pipes and towards the FBT. The problem with small batches is that the time to compensate for the unstable flow in the beginning, is short. Furthermore, operators are only able to take one or two samples to adjust the values. By the time the sample is analyzed, two thirds of the product are already in the FBT.

9 - Unstable Lager Beer

Lager Beer is beer which has not yet been filtered. This beer arrives at the UBT from the brewing process. Unfortunately, the alcohol, original extract and real extract values of the lager beer, which is in the UBT, fluctuate between batches. After the storage vessel, calculations are made for the operators with the adjustments they have to make during filtration. Next to the alcoholic strength, original extract and real extract, which are of importance during filtration, there are other important parameters. During brewing, filtration and in the BBT different measurements are taken. Process quality control parameters, which are of importance during brewing, are apparent extract, temperature, cell count, pH and flavor. In the BBT these parameters are for example apparent extract, alcohol, real degree of fermentation, pH, color, turbidity, CO_2 content, dissolved oxygen and flavor (Malting and Brewing, n.d.). If the parameters of brewing are low before the filtration process begins, filtering and blending the beer becomes more difficult since the operators have to make sure the values do not decrease more. In order for the beer to be filled into bottles, the values must be in-between the lower and upper specification limit.

3.2. INFLUENCE OF THE POSSIBLE CAUSES ON THE FILTRATION PROCESS

In this section the possible causes are analyzed and evaluated. This is the second phase of the Methodological Triangulation. Here the results found earlier are checked through follow up interviews with other operators and the outcomes are reviewed. The interviews are focused on the analysis of the problems and are highly structured. Again the operators, but also technicians, laboratory staff and employees from the companies that produce the inline instruments, are interviewed. Then the findings are reviewed and, where possible, verified by quantitative research. A categorization, based on the results of Methodological Triangulation is made in the end.

1 - Maintenance and Calibration

Through contacting *Anton Paar* it became apparent that *Grolsch* has a maintenance contract with the company. All instruments are calibrated after ordering them and before they are installed in the filter line at the company. The calibration happens with water and air at a certain temperature. After that there are no more calibrations. Exceptions are made if the process conditions of the instrument drastically change or the instrument is installed in a different area of the process. Then the instrument can be sent to Austria for a new calibration. This is not the case at *Grolsch*.

There are different types of maintenance: *Run-to-breakdown Maintenance*, *Preventive Maintenance* and *Condition-based Maintenance* (Slack, Brandon-Jones, & Johnston, 2013). Run-to-breakdown Maintenance means allowing the instrument to continue working until it fails and then repair or replace it. Preventive Maintenance eliminates the chance of a possible failure by checking, cleaning and replacing the instrument parts regularly in pre-planned intervals. Condition-based Maintenance only performs maintenance when the facilities require it. *Anton Paar* uses a mix of Preventive Maintenance and Run-to-breakdown Maintenance. Once a year, *Anton Paar* comes to check all the instruments. Here the condition of all parts are checked as well as the electric signals. The parts of the instruments are usually not replaced if they do not show significant problems and are used until they break down. The responsibility of maintenance is thus with *Anton Paar* and has recently been done successfully. In cooperation with Anton Paar it can be concluded that this is not a possible cause for the inaccurate measurements.

2 - Product-Specific Adjustment

At *Grolsch* there is no precise specification when to do a product-specific adjustment. Only a few operators are trained to perform one. At the moment, product-specific adjustments are only done if the original extract or alcoholic strength deviates for more than 0.5%. *Anton Paar* cannot recommend a maximum deviation value for the beers at *Grolsch*. The adjustment moment should be based on *Grolsch*'s quality objectives. Optimally the adjustment is done when the values are no longer in the lower or upper specification limit or if the values are fluctuating above or beyond the target for a long period. Different scenarios can be seen in Figure 3-5.

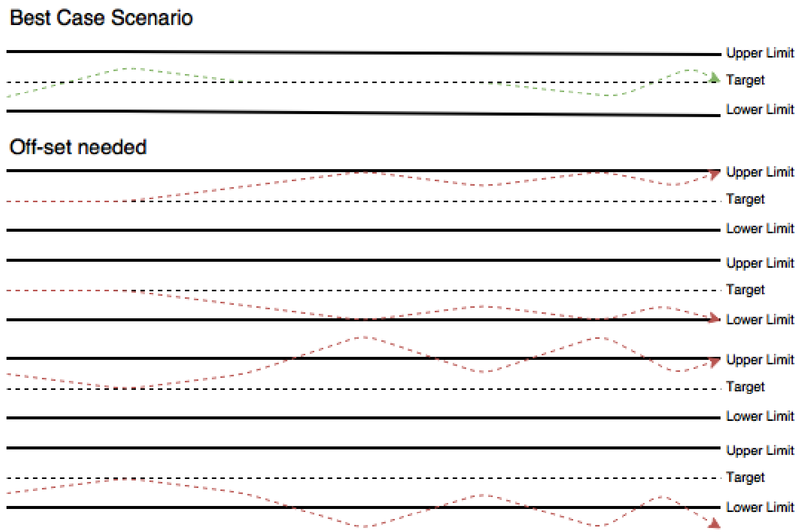

Figure 3-5 - Off-set of Measurements

Which products belong to which product group is dependent on the adjustment values that have to be stored in the mPDS. The composition of a product influences its adjustment. Especially, the density of a product is dependent on its components. Alcohol has a higher index of refraction than water. This means that refractometer measurements, which are made on a sugar solution once fermentation has begun, result in a higher reading than the actual solids content. Ethanol is less dense and lighter than water. An ethanol-sugar-water solution gives an original extract measurment that is low compared to the dissolved sugars (Chu & Thompson, 1962). This means, that the density of products with high sugar and alcohol compensate each other and the alcoholic strength, original extract and sugar content is shown lower than it is in reality. This is why Radlers and Pils beers should never have the same Haffmans number.

Table 3-2 - Filtration Restrictions

	Possible Filters				Possible Filters		
Name	**FL1**	**FL2**	**FL3**	**Name**	**FL1**	**FL2**	**FL3**
Pils Bnl	1	1	1	Miller (4,7%)	1	5	1
Pils Export	1	1	1	Tyskie	1	8	1
Navigator 8.0%	1	1		Lech	1	12	1
Palm	1	1		Pale Ale	1		
Premium Weizen	1	1		Weizen Cranberry	1		
Admiral (oud)	1	1		Herfstbok	3	3	
Kornuit fles/blik	1	1		Maximator / Kanon	5	4	4
Nav Black	1	1		Navigator 10% / Gladiator	5	11	1
De Klok Bier	1	1		Malt-Stender	9	6	
Miller (4,4%)	1	5		Radler 2%	14	14	
Lentebok	1	3		Radler 0.0%	14	14	
IPB High Gravity bulk	1	13		Radler 0.0 + Sirup	14		

FL = Filter line
HN = Haffmans Number

At *Grolsch* the Haffmans numbers are not assigned appropriately. Sugar and non-sugar beers are put into one group. Furthermore, products have different numbers on different filter streets. Even the groups to which the products are allocated are different. An example for this is the Navigator 10%. On filter line three it belongs to *Grolsch*'s Pils beers, on filter line two it has a Haffmans number on its own and on line one it is grouped with the Maximator, another high gravity beer. All this can be seen in Table 3-2. Establishing a more stable Haffmans number allocation, where products have the same number on each filter line and are allocated to the same group on each line, is important. This has as an effect that the product-specific adjustment is done in a more stable environment. For the adjustment procedure, *Anton Paar* has new Excel sheets that can make the work easier for the operators.

3 - Instrument Installation

After inspecting the installation of the instruments with specialists from *Anton Paar*, it seems that the two installation requirements described in the previous section have no influence on the process at *Grolsch*. *Anton Paar* recommends that instruments are installed at least 70 cm away from a turn in the pipe system. At *Grolsch* the Carbo 510 is installed approximately 90 cm away and therefore we can act on the assumption that no problems arise here.

The order of installation also does not trouble the efficiency of the process. The flow speed at *Grolsch* is high enough that the bubbles are dissolved quickly in the process. Even the flow speed on filter line one is still high enough. Next to that, the distance between the two instruments is approximately 70 cm, which gives the CO_2 bubbles enough space and time to dissolve in the beer. For those reasons we can also act on the assumption that the wrong implementation of the instruments is no possible cause for the inaccurate measurements.

4 - Regulation

After looking at the connections of the inline instruments the regulation becomes clearer. With the help of the instrument technicians the overview of the filtration process could be made, which can be seen in Section 2.1.. The *Proleit* system handles the automation of the whole brewing process. The *Brewmaxx* system is used to make recipes and to retrieve data from the process. *Proleit* and *Brewmaxx* work closely together. If a new filter run starts, they give a signal to the Haffmans PLC. This instrument now knows which beer is brewed and gives the Haffmans number to *Anton Paar*'s mPDS Evaluation Unit. The product-specific adjustment values have to be stored manually in the mPDS since Haffmans only allocates a Haffmans number through the use of five bits. As far as we can see, this process is working correctly. Moreover, the connections showed that Haffmans' and *Anton Paar*'s instrument do not work together. They only transfer data to each other. The data from the Carbo 510 is transferred to the mPDS and then the measurements from the Carbo 510 and DSRn 427 are used for the calculations of alcoholic strength and original extract and are then transmitted back to Haffmans. The blending values are also calculated with these transmitted measurements. After understanding this process better, it can be assumed that there are no problems within the regulation and data transfer.

5 - Pressure Difference

Louis Pasteur demonstrated in 1864 that potentially harmful micro-organisms in alcoholic beverages can be killed by heating the liquid for several minutes (Dilay, Vargas, Amico, & Ordonez, 2006). In almost all breweries this knowledge was used to stabilize their products for a certain period of time. Only at the end of the 19^{th} century, beer filtration was perfected (Hornsey, 2003). *Grolsch* has used both methods in the past. The pressure problem has been known by *Grolsch* for more than 10 years. The problem does not influence all products since most products are not pasteurized. Only products like the Weizen, where turbidity is wanted, are not filtered but pasteurized. This means that this problem is not the main cause for the inaccurate measurements Since this is a problem other people have already paid attention to, this possible cause will not be of relevance for this thesis. Furthermore, during the time of this research *Grolsch* decided to invest money in a buffer tank between the inline measurements and pasteurizing. This will solve the pressure problem.

6 - Reaction Time

In the brewery different liquids flow through a maze of pipes. Next to beer, raw materials, water and the cleaning liquids pass through the pipes. In order to guide these different liquids to the correct destination, valves are used. Valves have the purpose to seclude pipes or to connect them properly with each other. Two different valves can be seen in Figure 3-6.

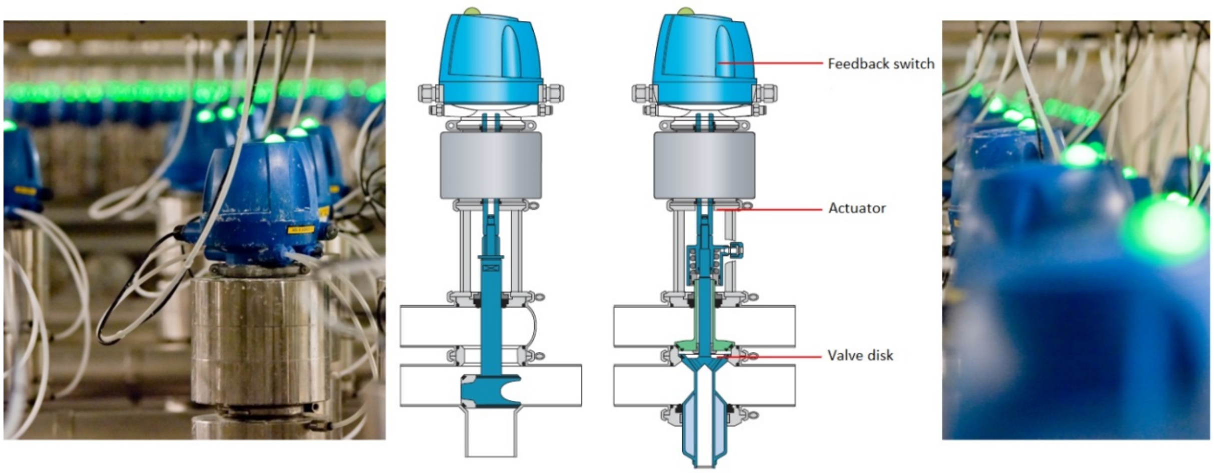

Figure 3-6 - Functioning of Valves

The operators state that the inline instruments and transmitted signals are not a problem. The bigger problem are the valves that have to adjust to the transmitted values from the automation system. The valves consist of different parts. The actuator causes the valve to open or close. The valve disks control this process. They actually connect or disconnect pipes from each other. The feedback switches receive signals from the automation system and ensure that the valve is activated.

The reaction time of the process is thus dependent on the valves. They regulate the amount of water that flows into the process during blending through opening and shutting the valve disks. If a lot of water needs to be added, the valve disks are open all the way. Sometimes the valves need some time to adjust perfectly. This means that they are moving up and down until they have found the right position. This is the reason why the operators occasionally feel that the reaction time is slow. However, this is a process that can hardly be improved. The only action that can be taken if a valve does not work sufficiently is checking the position of the valve disks. The actual position of the valve disks can be compared to the desired position by the technicians and be adjusted if the two positions differ.

The valves on filter lines two and three do not seem to be problematic. On filter line one though, the regulation valve that is responsible for the blending process, is sluggish. In conclusion it means that the long reaction time on filter line two and three can be disregarded. On line one though, a solution for the sluggish regulating valve needs to be found.

7 – Important Parameters

The unstable values of pressure and other variables arise because of the complexity of the filtration process. The beer passes the filters before it arrives at the inline instruments. One unstable value is for example the pressure. During the filtration process there can be changes in pressure. For example, if the KG filter filtered out many particles, the flow speed decreases since less beer can pass the filter and the pressure in the filter therefore increases. This causes fluctuating process conditions that are totally normal.

The previously described example with the beer, which is too cold for the filtration process, does not influence the measurements. The DSRn 427 has a build in temperature measurement. Therefore, all temperature influences are compensated.

Besides that, the blending of CO_2 influences the measurements of alcohol and original extract. *Grolsch* brews their beer according to *High Gravity Brewing*. This means that beer is brewed stronger and then blended with degassed water to reinstate the desired original gravity (Casey, Magnus, & Ingledew, 1984). High gravity brewing is a cost-efficient production process since the resources are used more efficiently. The capacity is higher than during a normal brewing process and less fermentation as well as storage tanks are needed (Galitsky, Martin, Worrell, & Lehman, 2003). The fermented beer contains CO_2. This gas is not evenly distributed in the storage vessel which means that its values thus fluctuate during the filtration process. The operators set a target value for the CO_2 in the automation system and then it calculates the CO_2, which needs to be added. The CO_2 is added to the product flow with pressure. If a lot of CO_2 is added, the product flow decreases because of the pressure from the CO_2 dosing point. At the same time there needs to be a certain counter pressure in order for the CO_2 to dissolve. Because these fluctuating process conditions, the measurements of original extract and alcohol fluctuate, too.

8 – Batch Sizes

As already mentioned, the batch size has an influence on the measurements of the inline instruments. When the filtration process starts, first 22hl rinsing water is pumped through the pipes and the filters. Just before the FBT, the water is routed into the disposal tank. Then the product flow starts. The first 65hl of the product flow is filtered and then, as the rinsing water, routed into the disposal tank. Now the actual filtration process starts. In Figure 3-7 a screenshot of a trend in the *Brewmaxx* system can be seen. The product flow, which is shown in the figure, excludes the rising water and the 65hl beermix that is dumped. The disposal is in the process flow before the inline instruments and therefore no measurements are taken from those liquids. In the figure the alcoholic strength and the original gravity measurements during a filtration process are shown. From five filter runs the fluctuating period is measured. The table with the calculations can be found in Appendix D. On average, during the first 33 minutes of a filtration process, the original gravity and alcoholic strength are unstable. In the screenshot the red error indicates this period. For an average process run of 2,000 hl, this would be an average of 195 hl beer, which is disposed. This is almost one ninth of a normal filtration run. If there is a short filtration run with 450 hl, the original gravity and alcoholic strength is fluctuating for almost half the filtration run. Under these conditions it is difficult to brew according to recipe since the time to compensate is short. For larger batches, this is not a problem because there is enough time to compensate for these fluctuating periods.

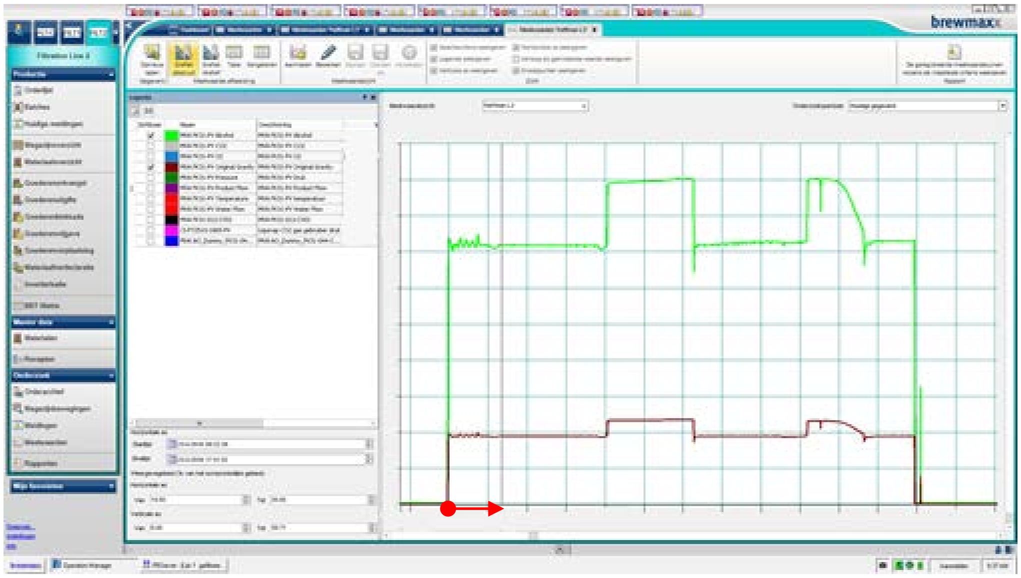

Figure 3-7 - Screenshot of a Filtration Run

Next, a statistical analysis of two Pils batches is carried out. The numbers are slightly changed for confidentiality reasons. Two batches, one with 890 hl beer and one with 4480 hl beer are analyzed with the normal distribution. The probability distributions can be seen in Figure 3-8. It shows the probability distribution of the original extract of a small and a big batch. The values from the measurements are indeed more accurate for the bigger batch. Here, not only the mean is closer to the target for which *Grolsch* aims but also the standard deviation of the bigger batch is much smaller than the one from the small batch. More accurate data can be found in Appendix E.

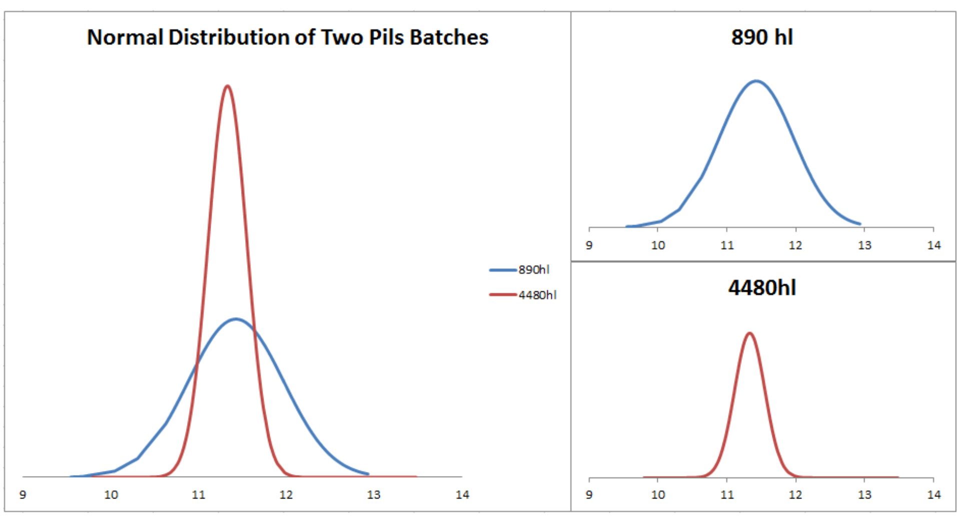

Figure 3-8 - Normal Distribution of Two Pils Batches

9 - Unstable Lager Beer

The Technical Brewers are working on a solution for more stable beer in the storage vessel. A more stable beer production allows the operators more freedom during the beer filtration. This problem will not be covered in this thesis though since it is the project from the Technical Brewers.

3.2.1. CATEGORIZATION OF POSSIBLE CAUSES

After all possible causes are reviewed, a categorization can be made. The categorization can be found in Table 3-3. Only causes two, six, seven and eight will be analyzed for their origins in depth. All other causes are unlikely to have caused the inaccurate measurements or are not relevant for this thesis.

Table 3-3 - Categorization Possible Causes

Possible Causes		Likeliness to be the main cause
1	Maintenance and Calibration	Unlikely
2	Product-Specific Adjustment	Likely
3	Instrument Installation	Unlikely
4	Regulation	Unlikely
5	Pressure Difference	Not relevant for this thesis
6	Reaction Time	Likely
7	Important Parameters	Likely
8	Batch Sizes	Likely
9	Unstable Lager Beer	Not relevant for this thesis – Project from Technical Brewers

For the four chosen causes, the origin of the problem will be found in the next section and possible solutions will be identified in Chapter 4. The first possible cause is the incorrect use of Haffmans numbers and the product-specific adjustment that is linked to the numbers. Furthermore, problems behind the long reaction time from the automation system and valves will be investigated. Then the unstable values of parameters, which are of importance for the filtration process, are discussed. Finally, the small batch sizes are being analyzed.

3.3. ORIGIN OF THE PROBLEMS BEHIND THE POSSIBLE CAUSES

In order to identify solutions for the problems, the origins of the problems have to be identified. This is an important step before the improvement possibilities will be discussed in the next chapter. If it is unknown where the problem originated, the chance is that the found improvement does not help. Some of the possible causes do not have an underlying cause or origin since this information is already known and described above. For these problems a broadening description is given in this chapter in order to gain a more detailed knowledge over the circumstances.

3.3.1. PRODUCT-SPECIFIC ADJUSTMENT

A few years ago all products of *Grolsch* were filtered according to the same Haffmans number, number one. At that point, no one knew what a product-specific adjustment is. The operators cannot remember when and why this changed. The oldest data that can be found is from 2010 when the recipes already had different Haffmans numbers. The operators assume that the Haffmans numbers were introduced after the acquisition of *Grolsch* by *SABMiller* in 2008. Since the acquisition, more beers are brewed, filtered and bottled at the *Grolsch* brewery. This was also the time when the trend to drink mixed beer and special beers begun. These beers are different from the normal beer products since sugar has to be added after the filtration process. With better technologies, better automation systems were made and the filtration process had to be more precise and stable. *Grolsch* always had the ambition of Continuous Improvement and this was probably one more reason to distinguish the beers.

Data from before 2010 is unfortunately not available. What is known is that some Haffmans numbers were changed. Unknown are the decision variables that were of importance. In 2015 an employee of *Grolsch*, started rethinking the Haffmans numbers. He wanted to make the filtration and especially blending process more precise. Unfortunately, this employee no longer works at *Grolsch* and he did not document his thoughts on this topic. The only data that can be found from him can be seen in Table 3-4. The Haffmans numbers before 25.04.2015, which are in light green, as well as the new numbers, which are in green, were documented from him. Both numbers do not match the numbers that can be found in the recipe at this moment, indicated in dark green. One thing that stands out is that he wanted to have one Haffmans number for each beer, no matter on which line it would be filtrated. The operators do not know how he came up with these numbers, but they all agree that it does not make sense that products have different Haffmans numbers on different filter lines. The table also shows that higher gravity and special beers are filtrated on the Pils Haffmans number.

Table 3-4 - Haffmans Numbers at Grolsch

Haffmans Number							
Products	before 25.04.2015			new 25.04.2015	right now 01.05.2016		
	Line 1	Line 2	Line 3	All lines	Line 1	Line 2	Line 3
Pils	1	1	1	1	1	1	1
Kornuit	1	1		1	1	1	
Tyskie	8	8	8	8	1	8	1
Lech	1	1	1	8	1	12	1
Amber	1			8	1		
IPB FG	1	1		8	1	1	
Mariner	1	1		8	1	1	
IPB HG	13	13		13	1	13	
MGD 4.4	5	5	1	5	1	5	
MGD 4.7	5	5	1	5	1	5	1
Navigator	5	5	5	2	5	11	1
Navigator 8.0	1	1		2	1	1	
Admiral	1	1		2	1	1	
Pale ale	1			2	1		
Maximator	4	4	4	4	5	4	4
Radler lime	14	14		14			
Radler mandarijn	14			14		14	
Radler grape	14			14			
Stender	9	6		6	9	6	
Radler 0	14			7	14		
Weizen	1	1		9	1	1	
Herfstbok	3	3		3	3	3	
Lentebok	3	3		3	1	3	

Thus the origin of this problem is especially the lack of knowledge about this topic. The one person that was responsible, left without leaving information on this. Contacting him is not a possibility. Setting new Haffmans number and documenting the process will make the process more stable and transparent.

3.3.2. REACTION TIME

Failures and inconsistencies of the valves can be caused by many factors. For example, the O-rings, elastomers or seat seals can wear off over time. But also temperatures or pressures outside the allowed range of operating parameters can damage the valves (Sparks, 2011). Especially if unexpected pressure spikes occur. Also the valve disk can be off its regular position. But well-designed processes should make sure that the process flow is successful and reduces potential failures or issues with valves.

Another origin for the error could be that it is programmed wrongly within the automation system. Many parameters are saved in the automation system. For valves and instruments, which are used during measuring and blending, most values are saved in the PLC from Haffmans. The regulating valve has different parameters for its settings, saved in the PLC. These factors should be checked and compared to the other filter lines. Often the values are changed unintentionally if problems in this section of the process occur.

3.3.3. IMPORTANT PARAMETERS

Inline measurements, as they are done by *Grolsch*, provide the highest level of quality and process control. The beer is continuously traced and it ensures high transparency of the process. When problems like the inaccurate measurements at *Grolsch* occur, inline instruments and automation systems provide the option to intervene in the process and to react to deviations. The operators see the happenings in the process in real time and they can react to them. The inline instruments are not made to react themselves, they are installed in the process to offer the brewery the chance to continually optimize the process (Günther, 2014). For the final adjustments it is important to have a highly accurate and reliable analytical measurement technique, which can compensate for the changes in the flow rate and fluctuating pressure (Corosys, n.d.).

The fluctuating process conditions are caused by the Beer Pressure Regulating Valve (BPRV). This valve consists of two parts. The Siemens SIPART PS2, an electropneumatic positioner for linear and rotary actuators and a SÜDMO regulating valve. The electropneumatic positioner forms a control system in connection with the actuator from SÜDMO. With the use of a servo potentiometer the current position of the actuator is detected and fed back as the actual value x. An electric current that is fed to the positioner forms the set-point w and the same time serves to supply the positioner in a two-wire operation (SIEMENS, 2006). The positioner is used to adjust and control the pneumatic actuators. The controller operates electropneumatically with compressed air as an energy supply. In order for all instruments to measure according to the right process conditions and in order to blend water and feed CO_2 into the process flow, the BPRV should generate a certain counter pressure in the process flow. Unfortunately, from the pressure measurements it can be assumed that there is no set-point set in the system. After looking into the automation system, it shows that there is indeed no set-point defined in the system. This means that the valve is open and does not regulate the pressure. But the pressure measurements also show that in the beginning of the filtration process, the pressure is low and then grows constantly. The counter pressure which is developed, is generated from the BBT. The BBT can only generate counter pressure if it is filled for more than one fourth. Especially if there is a change of BBT in the middle of a filtration run, deviations in the pressure can be seen.

At *Grolsch* there could be two problems. Either the communication between positioner and actuator is not explicit anymore, or the problem lies within the valve itself. At the moment the instruments and the automation system are not anticipating to the fluctuating conditions nor reacting to it.

3.3.4. BATCH SIZES

Batch sizes are an important aspect in a production company. They have to be agreed upon by the *Planning Department* and the Brewing Department. The batch size differs depending on the beer type, packaging type and per process run. Beer types with high demand can be produced in bigger batches. This happens because the risk that these products exceed their shelf-life is low. The holding costs for these products are small most of the time, too. *Grolsch* replaces their inventory every month. For each hectoliter beer the operating costs of bigger batches are much lower than of smaller batches. Products with low demand like the Weizen, Stender and Bokbier, cannot be brewed in big batches since these are seasonal products with low demand. Another reason is the lack of lager beer in the storage vessels. Lager beers are the main ingredient for the finished product. Further, it is necessary to have sufficient resources. Resources can be sugar or concentration for the mixed beers. The last reason for small batches is the capacity of the filling lines and BBTs. If there is not enough capacity for bigger batches, small batches have to be brewed and filtered. The handled minimum batch sizes at *Grolsch* is the more than double the capacity per hour on filter line one and slightly more than the capacity per hour on lines two and three. These restrictions are agreed upon since they can bear the quality and risk management regulations.

3.4. CONCLUSION

Nine possible causes for the inaccurate measurements of the inline instruments are identified, analyzed and evaluated. After analyzing all of them, it can be concluded that the incorrect use of Haffmans numbers and wrong or irregular product-specific adjustment, the long reaction time from the automation system and valves, the unstable values of parameters and the small batch sizes are the main influences on the inaccurate measurements of the filtration process. In conclusion it can be said that there are multiple causes for the inaccurate measurements and the inconsistent and unstable performance of the filtration process.

4. IMPROVEMENT POSSIBILITIES

This chapter investigates options for improvement of the main problems behind the inaccurate measurements of the inline instruments. First, the importance of improvement and the vision of improvement at *Grolsch* are discussed. Then, for the four main problems options of improvement are investigated. Finally, the principle of process control is introduced.

4.1. IMPORTANCE OF IMPROVEMENT

Continuous Improvement is one theory a company can adapt in order to improve the performance of the operations functions. *Grolsch* states on their website concerning vision, ambition and values that they learned from their experience that you have to improve yourself continuously (*Grolsch*, 2015)[4]. One of the operations principles says that improvement is the ultimate objective of operations and process management performance (Slack et al.). *SABMiller* states the following in their Focused Improvement Implementation Framework: “Operational excellence is entirely dependent upon a resolute process of Continuous Improvement” (SAB Miller, 2011). Continuous Improvement is an approach that assumes that many small improvement steps improve the performance of a process. The approach expects that every small step towards improvement will be followed by more small incremental steps. The advantage of small improvement is that it is easy to continue with more steps. As Slack et al. (2013) says, with “Continuous Improvement it is not the rate of improvement which is important; it is the momentum of improvement” (p. 544). What is meant by this quote is that it does not matter how extensive the improvement is, but that it is important that improvement happens regularly. During the research at *Grolsch* it becomes clear that the whole research is also part of a Continuous Improvement cycle. *SABMiller* states that: “Focused Improvement is the best practice of ensuring ongoing improvement in the organization’s key performance areas by reducing or eliminating waste and variability”. According to the company Focused Improvement is a subset of Continuous Improvement in the context of lean manufacturing. They assume that there is a scarcity of resources, and aims to apply scarce resources to make improvements where it makes the biggest impact. Focused Improvement is therefore the difference between being busy and adding value (SAB Miller, 2011).

For the Continuous Improvement and Focused Improvement approach, the quality standards of *Grolsch* and *SABMiller* are of importance. According to the *SABMiller* group Quality Management is “the act of overseeing all activities and tasks needed to maintain a desired level of excellence” (Dresse, 2014). This includes Quality Planning as well as Quality Assurance, but also Quality Control and Quality Improvement. Quality Management therefore uses quality assurance and control of processes as well as products to achieve more consistent quality.

4.2. IMPROVEMENTS

The improvement possibilities for the four main problems are described below.

4.2.1. IMPROVEMENT OF THE PRODUCT-SPECIFIC ADJUSTMENT

The research in Chapter 3 shows that *Grolsch*’s number one priority should be to improve the use of Haffmans numbers and do a correct product-specific adjustment. At the moment, this has a too low priority and is not done correctly.

[4] “Als die ervaring ons één ding heeft geleerd, dan is het wel dat je jezelf voortdurend moet vernieuwen.”

Adjustment by Constant Offset

The adjustment should always be done during normal production. For the calculation of the adjustment factors ideally samples from different batches of the same beer are taken. The adjustment works according to a linear function, $Concentration(adjusted) = Concentration(initial)\ x\ \{Gain - factor\} + \{Offset\}$. This can also be seen in Figure 3-2. At the moment, only original extract or alcohol is corrected at *Grolsch*. It is much more efficient to correct both factors. If the same concentration is adjusted, then only the offset is used. The adjustment will not change the slope of the curve. If subsequently a much lower value is measured, the adjustment can give a distorted picture of the measurement. This is because an extrapolation of the calibration line is done and regression would be used to determine the values in the undefined intervals. In order to prevent this the values, which need to be corrected, should be spread over the whole measuring range. An adjustment is only as accurate as the width of the range of the measurements. In addition, it is important to only perform an adjustment if the actual measuring values were stored at sampling and an adjustment is indeed necessary. Otherwise misadjustments will occur or error messages will be shown. Since this research shows that many factors, which are not stated in *Grolsch*'s manual for product-specific adjustment, are of importance for the adjustment procedure, the manual should be revised and updated. Also the maximum deviation is re-calculated. This is done by comparing the target values to their Upper and Lower Specification Limit. The maximum deviation, which is now allowed, is half of the average of the percentual difference between these values of all types of beers. The calculations for this is shown in Appendix F. Product-specific adjustment needs to be done if

1. the deviation of alcoholic strength is larger than 0.75%
   and/or
2. the deviation of original gravity is larger than 1.0 %.

New Haffmans Numbers

Another important aspect for *Grolsch* is the reallocation of Haffmans numbers. Two different improvement options are identified and described below. Since *Grolsch* has had this problem for a long time, the important factors for the allocation were identified and new product groups were established within the context of this research. The new allocation of product numbers for both options, can be found in Figure 4-1. *Grolsch* should choose and implement one of the options.

Option 1: Product Groups

To arrange the products in groups, different parameters are of importance:

- Quality range
- Filtration Temperature
- Values for the alcoholic strength and original extract
- Safed adjustment values of the mPDS Evaluation Unit
- Additional ingredients(sugar)

To group the products, first all products, which are at the moment still produced at *Grolsch*, are put into a list. Then, the alcoholic strength and original gravity are looked up for each product. The quality standards, thus the allowed range of deviations for the main parameters, are important. With the rule of proportion, the percentual difference between products is calculated. It is especially important that the percentual difference of the alcoholic strength between two beers is the same as the percentual difference of original extract. Next, the filtration temperature of the different products is compared. Products that differ cannot be grouped together. Moreover, the recipe of the products is analyzed. If products have additional sugars or other additional extracts, they cannot be grouped with products without those. Finally, the values that are saved within the mPDS Evaluation Unit at that moment are compared. Values of Haffmans numbers that are similar, can now be grouped together.

The advantage of product groups is that less time is needed for the initial adjustment of the products. In the future, product groups can be adjusted and not individual products. Thus in total, less time is needed for adjustments.

Option 2: Individual Haffmans Numbers

The allocation of individual numbers is easier. Products are just allocated with new numbers. The export and domestic products of one type of beer are still grouped together.

The advantage of individual product numbers is the accuracy of the measurements. The measurements throughout the filtration process and the instruments are now adjusted to this specific product. This means that more time for adjustment is needed, but that adjustments probably do not need to happen too often.

		Group Hafmans Numbers			
Name	**Nr.**	**FL1**	**FL2**	**FL3**	**Sugar**
Pils Bnl fust	242368	1	1	1	
Pils Bnl fles / blik	242369	1	1	1	
Pils Export fust	242370	1	1	1	
Pils Export fles / blik	242376	1	1	1	
Kornuit fles/blik	242385	1	1		
Malt-Stender	242381	2	2		
Herfstbok fles / blik	242362	3	3		Yes
Herfstbok fust	242363	3	3		Yes
Lentebok fles / blik	242364	3	3		Yes
Lentebok fust	242365	3	3		Yes
Tyskie	242379	4	4	4	
Lech	242380	4	4	4	
De Klok Bier	242383	4	4		
Amber	242361	5			
Premium Weizen fust	242386	5	5		
Premium Weizen fles / blik	242375	5	5		
Miller (4,4%)	242372	6	6		
Miller (4,7%)	242384	6	6	6	
Miller 4.4% Fust	242377	6	6		
IPB High Gravity bulk	242382	7	7		Yes
Pale Ale	242389	7			Yes
Nav Black	250011	8	8		Yes
Navigator 8.0%	242373	8	8		Yes
Maximator / Kanon	242366	8	8	8	Yes
Navigator 10% / Gladiator	242367	8	8	8	Yes
Weizen Cranberry	253070	13			Yes
Radler 0.0%	242392	14	14		Yes
Radler 0.0 Grananas	250242	14			Yes
Radler 0.0 Ice-T	250243	14			Yes
Radler 2%	242387	15	15		Yes
Radler Mandarin	242390	15			Yes
Radler Grananas	242391	15			Yes
Palm-loon-fles	242404	40	40		
Rodenbach	242405	40	40		
Grimbergen Blond	242406	40	40		
Grimbergen Dubbel	242407	40	40		
Grimbergen Tripel	242408	40	40		

		Individual Haffmans Numbers			
Name	**Nr.**	**FL1**	**FL2**	**FL3**	**Sugar**
Pils Bnl fust	242368	1	1	1	
Pils Bnl fles / blik	242369	1	1	1	
Pils Export fust	242370	1	1	1	
Pils Export fles / blik	242376	1	1	1	
Amber	242361	2			
Herfstbok fles / blik	242362	3	3		Yes
Herfstbok fust	242363	3	3		Yes
Lentebok fles / blik	242364	3	3		Yes
Lentebok fust	242365	3	3		Yes
Miller (4,4%)	242372	4	4		
Miller 4.4% Fust	242377	4	4		
Miller (4,7%)	242384	5	5	5	
Malt-Stender	242381	6	6		
Tyskie	242379	7	7	7	
Lech	242380	8	8	8	
IPB High Gravity bulk	242382	9	9		Yes
De Klok Bier	242383	10	10		
Kornuit fles/blik	242385	11	11		
Navigator 8.0%	242373	12	12		Yes
Navigator 10% / Gladiator	242367	13	13	13	Yes
Radler 2%	242387	14	14		Yes
Radler Mandarin	242390	14			Yes
Radler Grananas	242391	14			Yes
Radler 0.0%	242392	15	15		Yes
Radler 0.0 Grananas	250242	15			Yes
Radler 0.0 Ice-T	250243	15			Yes
Maximator / Kanon	242366	16	16	16	Yes
Pale Ale	242389	17			Yes
Premium Weizen fles / blik	242375	18	18		
Premium Weizen fust	242386	18			
Nav Black	250011	20	20		Yes
Weizen Cranberry	253070	21			Yes
Palm-loon-fles	242404	40	40		
Rodenbach	242405	40	40		
Grimbergen Blond	242406	40	40		
Grimbergen Dubbel	242407	40	40		
Grimbergen Tripel	242408	40	40		

Figure 4-1 - Appointment of Haffmans Numbers

The costs of implementation for this solution are low because the initial allocation of Haffmans numbers happens during normal production. The support of the *Anton Paar*'s employees is free too, since *Grolsch* has a contract with them. This means that *Anton Paar* could be consulted before the actual implementation. Nevertheless, the option identifying individual product numbers would be recommended for *Grolsch*. This option is more difficult to implement, but in the end it will result in the most stable process.

4.2.2. IMPROVEMENT OF THE REACTION TIME

The valves are one of the most complex instruments of the filtration process. There are hundreds of them and all are controlled through one system. During the cause of this research, it became apparent that often irregularities occur whose causes are not identified. In order to improve this, a procedure should be introduced. If irregularities concerning the valves occur, the checklist below should be evaluated. Moreover, the adjustments done in the PLC and automation system should be documented. This way the values of different filter lines do not need to be compared, but they can be taken from the saved documentation. For these possible causes there are also no costs involved for *Grolsch*. The actions described below, can all be done could all be done by employees.

Valve Irregularity Procedure

Once an irregularity or defect in the valves occurs, these guidelines have to be followed (Sparks, 2011):

1. Identify the reason for the defect or failure. This can for example be the seat, body, actuator, etc. Also check the values, connections and set points within the PLC and automation system.
2. Take necessary troubleshooting steps to identify the root causes for the problem. If possible resolve the problem while the valve is in place.
3. If necessary, remove the valve from piping.
4. Follow the disassembly and maintenance procedures to resolve issue and reassemble the valve.
5. Re-install the valve after the problem is fixed.
6. Test and monitor the valve to ensure proper function before the production startup. If values are changed within the automation system, check if the deregulations in the process flow are gone. Otherwise test other values to find the optimum.

4.2.3. IMPROVEMENT OF THE IMPORTANT PARAMETERS

There are two different problems concerning unstable values of parameters. One improvement option regarding each problem is described below.

Beer Pressure Regulating Valve

CO_2 is dissolved in beer during the filtration process. But the solubility is dependent on two important parameters: temperature and pressure. The relationship is described in Equation 4-1.

Henry's law states: "At a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid" (Yamuni, n.d.). The CO_2 gas solubility increases as beer liquid temperature decreases and decreases as beer liquid temperature increases (Tran & Wan, 2013). Therefore, the colder the beer the quicker the dissolution of CO_2 and this results in a more efficient use of CO_2. For *Grolsch* it is important to find out what the counter pressure in the line should be. While CO_2 is fed into the beer, which is called beverage carbonation, CO_2 is dissolved under pressure. In an enclosed system, the CO_2 remains in the beer since the pipe is kept under pressure and since pressurized beverage buffer tanks are used. These make sure that after a certain time in the tanks an equilibrium will be established between the pressure of the CO2 in the beer and the corresponding pressure in the BBT(Wilson & Medling, 2006). The pressure required to do so, depends on the CO_2 content and the temperature of the liquid. If the CO_2 content is high, more pressure has to be used at a given temperature and the other way around (Ghose & Nair, 2013). Solubility also depends on the other materials that are dissolved in the beer (Unclassified, 2011). Since this dependence is weak, it can be disregarded here.

Equation 4-1 - Solubility of CO_2 (Haffmans, n.d.)

The measurement of CO_2 in most cases is carried out by Henry's Law. It describes the relationship of a concentration and its pressure. The solubility of CO_2 is defined as:

$$H^{cp} = \frac{c_a}{p}$$

$H^{cp} = Henry's\ law\ constant\ describing\ the\ solubility$
$c_a = the\ solubility\ of\ a\ gas\ at\ a\ fixed\ temperature\ in\ a\ particular\ beverage$
$p = the\ partial\ pressure\ of\ that\ species\ in\ the\ gas\ phase\ under\ equilibrium\ conditions$

The constant of Henry's law is dependent on the temperature of the liquid. Equilibrium is then achieved through routing the solution through the mixing tube. Then the instrument can calculate the CO_2 content and the overpressure with the Haffmans formula:

$$CO_2 = A\ x\ (P + B)\ x\ e^{(C + \frac{D}{T+273,15})} + E$$

$A = compensation\ factor$
$B = airpressure\ during\ calibration\ from\ pressure\ gauge\ (bar)$
$C = product\ specific\ factor$
$D = product\ specific\ factor$
$E = factor\ for\ CO_2 - unit\ p_{20}.$
$P = pressure\ (bar)$
$T = temperature\ (°C)$

Example	
Product	Beer
Original Extract	12° Plato
Apparent Attenuation	80%
Constant C	-10.74
Constant D	2617.25

The pressure thus depends on a couple of parameters in order to dissolve the CO_2. In 2008 the company Haffmans calculated the set-point for the BPRV. This valve is used to establish a constant pressure throughout the CO_2 dissolving phase. In the documentations from 2008, Haffmans says that the valve needs to be set to seven bar. The operators on the other hand, are sure to have used a set-point of five bar until the data disappeared from the system recently. After contacting Haffmans, they explained that the pressure is connected to the setting of the pump in the filtration line. This pump is responsible for a constant flow in the section where the measurements are taken. The pressure transmitter from this pump determines the set-point of the BPRV. A way to test the value of the set-point is to open this valve all the way during normal production and when the BBT is filled high enough to give a certain counter pressure. In the statistics of *Brewmaxx*, it can be seen that the value of the pressure measurement is between four and five bar if this is done. This means that the set-point has to be in this range, too. A slightly higher set-point is recommended in order to insure the best conditions. Haffmans thinks that the process condition must have changed in order for the valve to have a lower set-point now.

The programming team from *Proleit* should put an adaptability box for the set-point of the BPRV into the automation system. This way operators can change the value settings manually. It is also important to put a set-point into the system.

In the future, the optimal set-point from the valve should be determined for each product or product family. Set-points between four and seven bar should be evaluated on their influence on the process flow.

The CO_2 content of a beer depends on the product type and the packaging material. During Radler filtration, for example, less CO_2 is added than during the filtration of normal beer. There is also a difference between beer which is filled into kegs and beer which is filled into bottles. The content can be seen in Table 4-1. During filling some of the CO_2 vanishes. The amount which vanishes is higher for bottles than for kegs, which means that for bottled products more CO_2 needs to be added during filtration. With different amounts of CO_2, the set-point of the valve changes too. It should be tested which set-point is optimal.

Table 4-1 - CO_2 Content Dependent on Product Types

CO_2 Content		
	Bottle	**Keg**
Radler	Medium	/
Beer	High	Low

The correct implementation will be expensive for *Grolsch*. For one, the programmers from *Proleit* need to receive payment for the changes they have to make within the automation system. This is a small project for them. Further, *Grolsch* should ask for an offer from Haffmans for specific calculations of the counter-pressure. This should then be done for all their products on all three filter lines. In order for new products to be brewed, a training for future calculations or a contract with Haffmans is necessary.

Difference in Tank Content

For the planning and the right composition of the beer, the measurement of the amount of beer in the BBT is of importance. This value is measured with two different meters. A flow meter and a pressure meter. The operators can only dodge their products by using the pressure meter. Unfortunately, they cannot use the flow meter, which is more precise. If there is a big difference between the pressure and flow measurements, it is difficult for the planning to be accurate. If more beer than expected is in the BBTs, the filling lines need more resources than thought at first. The problem of these inconsistent values has been dealt with before. By resetting the meters and replacing some of them, the efficiency has been improved. A recommendation for *Grolsch* is to keep track of the deviation between these values. If there are tanks that show big deviations for a longer period of time, the meter should be reset or replaced. In order to have minimum costs, the meters should always be reset a few times before the choice is made to replace them.

4.2.4. IMPROVEMENT OF THE BATCH SIZES

The Planning Department at *Grolsch* has a difficult job to do. The planning is dependent on the operations in the whole brewery. This means that changes occur if there are not enough raw materials or if there are problems during brewing, filtration or filling. This has as the outcome that the beer cannot always be planned in big batches.

Nevertheless, changes have to be made in order for the filtration to filter and blend the beer according to the quality standards. The planning at *Grolsch* is a rolling wave planning (Haugan, 2002). This means that the planning is done in waves since it is often not possible to foresee future activities. As time proceeds details become clearer. Activities in the near future are planned in detail whereas activities in the longer future are planned roughly and left for future detail planning.

Grolsch uses a pull strategy. This means that they start their actions by the market and then go towards the processes of the company. The demand requests the supply and resources needed (Corniani, 2008). They start by analyzing the demand of their customer. With this demand they plan when, which type and how much beer has to be filled into bottles, cans or kegs. After this, the filtration runs and the size and type of brewing batches can be planned. For the problem concerning the batch sizes, different adjustments are possible. It needs to be said, that this problem will be a lot smaller if the inline instruments measurements and calculations are more accurate.

Option 1: Bigger Batches

The first option for improvement is to increase the minimum batch size. The minimum batch sizes were not calculated, but are an estimate from the project managers. From their point of view, the batch sizes on line two and three have to be at least this big in order to balance the beer and have a high quality end product. An increase of the batch sizes without an increase in performance efficiency though, is not possible. There are a few restrictions for the planning especially regarding all kinds of resources.

Option 2: Slower Filter Runs

The second option is decreasing the flow speed. The flow speed could be decreased by up to 50% without having effect on the quality of the beer. On the one hand, a decreased flow speed gives the operators more time to react to the process flow. On the other hand, a decreased flow speed implicates longer filter runs. Longer filter runs mean that less beer can be filtered within 24 hours.

The Planning Department is not happy with this idea. This gives them less possibilities to be flexible. Often, the filtration process already takes too long since problems occur.

Option 3: Circulating the Beer

The last option is circulating the beer for a certain period of time. The operators always have to take at least one sample in the beginning of the filtration. Even with improved measurements from the instruments, this sample will have to be taken. This way the filtration will take 15 to 20 minutes longer, the amount of time it takes to analyze a sample. Circulating the beer does further not harm the process. The idea for this process is as following:

1. Let the first part of the batch pass the filter and inline measurements until the measurement values are stable. This will approximately be 200 hectoliters.
2. Take a sample at the line and put the line into circulation.
3. Analyze the sample and manually change the values within the automation system if necessary.
4. Put the flow out of circulation.

The costs of the three options cannot be determined right away. At this point it has to be said though, that minimum costs should not be the decision making factor for the implementation. The whole brewing industry centers around brewing a high quality product. When making a decision in this matter, the options which promises the highest quality should be chosen. From the research standpoint, option one should be chosen for the long run. This option can give the brewing and Planning Department the highest quality product. This could have consequences on the manner of production planning though.

4.3. PROCESS CONTROL

This thesis shows that *Process Control* is one of the most important aspects in a brewery. Specifically, Operations Control has the objective to control the operation of the brewing process within the functional parameters (Richmond, 1994). Extensive machinery and instrumentations are used at *Grolsch* to design adequate control measures and quality standards for all phases of brewing. As a consequence, they expect the beers to be of high quality and as “uniformly pleasing as possible” (Richmond, 1994). Each stage of the beer-making process requires controls of a multitude of variables. The variables are different depending on each process, but all are important for the end product, which is going to the customer. Complete understanding of these variables will define the quality objectives of the beer and their influencing factors on other variables. The measurement of the variables within the filtration process is the key process analyzed and inspected throughout this research. Like Christian Günther (Günther, 2014) said in one of his articles in Brauwelt International: “It is always better to precisely control a process in terms of measurement rather than to run via a fixed empirical value plus a safety margin. “

4.4. CONCLUSION

This chapter gives an answer to the question: “What should *Grolsch* do to improve the filtration process?” *Grolsch* is a company that likes the concept and attitude of Continuous Improvement. This whole project is based on Continuous Improvement. For all the problems that partly cause the inaccurate measurements, improvement possibilities were considered. For some of the identified problems, more than one option of improvement was found, though the best, from the standpoint of this research, option was chosen. The next chapter will include the conclusion as well as recommendations for the future.

5. CONCLUSION AND DISSCUSSION

This chapter consists of the conclusions, recommendations and limitations within this research project. Section 5.1 contains the conclusions of this research. General recommendations and implementation plans are given in Section 5.2. Section 5.3 discusses the limitations as well as the recommendations for future research.

5.1. CONCLUSION

The filtration process at *Grolsch* has been unreliable in the past. This is why the Brewing Department wished for an analysis of the process. The inaccurate measurements of the inline instruments during the filtration process are the focus of this research. This problem leads to the main research question stated below that will be answered in the following:

How can the inaccurate measurements of the inline instruments within Brewery Grolsch's filtration process be improved?

This research identifies and analyzes ten possible causes of the inaccurate measurements. After evaluating and categorizing them, four problems are identified as the main causes. These are the product-specific adjustment, reaction time, important parameters and the batch sizes.

Keeping in mind the problems detected at *Grolsch* and the solutions found earlier, these specific conclusions regarding the four main problems are developed.

Grolsch should rethink their manual for the product-specific adjustment. Right now it is unclear and unstructured. A better manual would make the work for the operators easier. The new Excel sheets from *Anton Paar* should be used for the adjustment procedure in the future. This makes the adjustment quicker and less complicated. The new manual should also be handed to *Anton Paar* to check if the procedure is as they recommend. For the product-specific adjustment two different improvement options are mentioned in the previous chapter. The options are individual Haffmans numbers or group Haffmans numbers. For *Grolsch*, individual Haffmans numbers would be recommended since the products can then be blended with more accuracy. The time needed for the initial implementation is longer than for the other option. Though, individual adjustment will then have to be done less in the future.

Valve failure or malfunction is a problem that often occurs in breweries. Hundreds of valves are installed in a maze of pipes. Different liquids flow through them and the tasks of the valves differ. If irregularities or abnormalities occur, there should be a procedure for operators and technicians to follow. Changes and especially saved values should be better documented to decrease the problem detection period.

In this research, one valve is introduced in a special context. The BPRV is important for the CO_2 content of the beer. Right now, *Grolsch* needs to put the set-point of the BPRV into the automation system as soon as possible. This way operators can change the value manually. It is also important to check what happens if a set point is introduced. Set-points between four and seven bar should be evaluated on their influence on the process flow. The value that influences the process flow in the best possible manner, should be set as the set-point. For the long term, *Grolsch* should analyze the relationship between temperature, CO_2-content and pressure for each product or product packaging family. Temperature and CO_2-content are recipe-parameters and are defined for each product individually. Since these values have an influence on the set-point of the BPRV, each product should have an individual pressure set-point. For the analysis, Equation 4-1 should be used. For the future, it would also be recommended to make the pressure set-point a recipe parameter.

The department that is coordinating most of the activities in the brewery is the Planning Department. They analyze the demand, plan how many products need to be packaged and also how much beer needs to be brewed and filtered. One important measurement is the content of the BBT. With this value, it can be calculated how many products are going to be filled and how much packaging material is necessary. In order for these values to be more accurate, the flow and pressure meters need to be reset or replaced regularly. The Planning Department should document all the activities of these instruments and communicate deviations and errors to the Brewing Department or the technicians.

Another action that needs the combined efforts of the Brewing and Planning Department are the batch sizes. For the short term, circulating the beer is a good and efficient solution to reach the quality standards with a minimum of cutbacks. For the future, a product based minimum should be calculated for each product. Especially beers where a lot of sugar and water needs to be added, should be filtered in larger batches. The minimum that is handled right now was not calculated and is a pure estimate. Calculation of the minimum with regards to the quality standards would make the filtration run more efficient. The employees of the Planning Department should be consulted regarding all underlying factors that are of importance.

Process Control means controlling all processes throughout the brewery. All the processes have to be harmonized in order for the company to succeed. Process Control should be one of the focus points of *Grolsch*. This means that in the end operators should still take samples of the beers. In such a complex process, irregularities occur almost on a weekly basis. However, this research will decrease the amount of samples that operators have to take on a daily-basis.

The variables that had to be operationalized are the inaccurate measurements of the inline instruments with the key variables being the percentage of deviation in the measurements between the inline instruments and the Quality Control Laboratory. Since the findings from this research are not yet implemented, it cannot be said how big the deviation between those values truly is. Though it can be said with certainty that *Grolsch* can secure a better process with smaller deviations between the key variables if the above described actions are taken. The process flow will be more stable and efficient. This will be a cost-saving factor in the long run and enable the operators to react fast to problems concerning the filtration process.

5.2. RECOMMENDATIONS

The recommendations are split into two sections. The first section describes the general recommendations that stood out in the time of the research. The second section describes the recommendations for the implementation of the conclusions.

5.2.1. GENERAL RECOMMENDATIONS

Grolsch is a company that focusses more on short term fixes than seeing the long term advantages. This was noticed in different departments and in cooperation with different employees. Especially the Brewing Department should start to work more towards the long term improvements, as far as the company objectives allow them to. Some noticeable improvement possibilities are named in the following section.

Instruction Manuals and Trainings

Many operators and other employees do not exactly know what happens during all phases of the filtration process. Especially the methods of operation from the instruments are unknown. This can be improved by letting them read and understand the instruction manual or letting them attend training sessions. This should be done in order to understand the proper steps of assembly as well as disassembly, to understand the maintenance procedures as well as troubleshooting actions. In the end, this can help the employees to find solutions and origins of problems faster.

Preventative Maintenance Routines

For many instruments the maintenance and calibration procedures, intervals and the people responsible for the process are unknown. A list of the parties responsible for the actions would help all people involved. A list with all the names and job descriptions of the contributors to this research can be found in Appendix G. Especially establishing a Preventative Maintenance routine in which common failure parts are replaced before they fail and are checked on a regular basis could help *Grolsch*.

Knowledge Management

Knowledge Management is the process of capturing, using as well as sharing knowledge (King, 2009). This is important in order for a department to work efficiently. Especially knowledge sharing and documentation are important aspects, which can be improved at *Grolsch*. Often, only one person is instructed at *Grolsch* and has the knowledge over his or her specific area of operation. A good example is the employee, who left *Grolsch*, resulting in the loss of knowledge about the Haffmans numbers. At a big company like *Grolsch*, it should be no problem to have more than one specialist in a specific department. In addition, documentation is of great importance. If instruments are calibrated or numbers are changed, these actions should be documented for future reference. Product specific parameters should also be documented better. Right now, not even project documentation can be found in the database. This information could help to increase the speed and efficiency of problem determination.

5.2.2. RECOMMENDATIONS FOR THE IMPLEMENTION

The implementation of three solutions will be described below. These three are seen as the implementations worthy of a description.

Implementation of Haffmans Numbers

The implementation of the product-specific adjustment starts with the beer that comes from the brewing process. All the important parameters of this beer need to be within the target values in order for the process to begin. If they are not, the implementation should be postponed onto a later point in time.

If the parameters of the beer are within the target, the implementation can take place. Before the filter run is started, the Haffmans number has to be changed in the recipe. If this is done, the filter run can be started. When the measurements of the alcoholic strength and original extract are stable, the first sample should be taken and analyzed in the laboratory. In intervals of 30 minutes, two other samples need to be taken and analyzed. The deviations between the laboratory measurements and the inline measurements have to be put into the mPDS Evaluation Unit and saved under the new Haffmans number. Now, the allocation has taken place. During the next filtration runs, the parameters should be monitored and a new adjustment should be done if necessary. In case the option with the group Haffmans number is chosen, the adjustment should be done with batches of different sorts of beer.

Testing the Right Counter-Pressure

For precise calculation of the right pressure, the company Haffmans should be contacted. Another option is testing the right pressure. For this, the filtration needs to be in normal operation. Different products and product packaging families need to be tested. The values cannot be transferred to another filter line, but have to be taken individually on each line. The test should take place at the beginning of the filter run. The valve should be tested in between four and six bar in steps of 0.1 bar. In intervals of 5 minutes, changes should occur. During testing, the process needs to be monitored. If the pressure in the line becomes more stable, the values should be changes in steps of 0.01 bar and in intervals of 2 minutes. The pressure that results in the most stable process, should be taken as set-point.

Identifying Optimum Minimum Batch Sizes

For the identification of the best minimum batch size specific implementation recommendations cannot be given. Though, factors that should be taken into account have been found during this research:

- The quality target of the beer should be the focus.
- Demand and its uncertainties have to be a factor in the calculations.
- Additional ingredients and their effect on the process need to be identified.
- The filter line, where the specific type of beer is mostly filtered, should be identified.
- If the optimum batch size is really small, it should be evaluated if it is possible to only filter this type of beer on line one due to the slower flow.

5.3. LIMITATIONS AND FUTURE RESEARCH

Every research has its limitations. The limitations are those characteristics of design or methodology that impact or influence the interpretation of the findings of the research.

The implementation of the improvement options is not part of this research. Implementation options are described in the earlier section, but the options will not be implemented with my help. In the end it is the choice of *Grolsch* which options to implement and how to do so.

The main analysis was done for filter lines two and three, the bigger filter lines. This does not mean that all the problems exist on line one as well. Since this line operates slower, many problems are not as severe as on the other two lines.

Furthermore, this study is solely focused on the technical standpoint of the process. The limitations concern the analysis of human interaction in the process.

In addition, the quantitative research could not be done as extensively as planned in the beginning. Often, the data to prove the existence of the problems, is not available or not measurable. There is also a lack of prior research studies concerning inaccurate measurements of inline instruments. The quantitative research that was possible, is mostly done with small sample sizes and not extensively due to the time restrictions. This is also why additional research is recommended. The study has therefore no external validity. If the problems arise again in the future, *Grolsch* can revert to the findings.

5.3.1. FUTURE RESEARCH

During this research several subjects were found that are interesting for future research at *Grolsch*. It is recommendable for *Grolsch* to:

- Analyze the minimum batch size per beer type and per product line regarding the desired quality standards.
- Analyze the pressure set-point for different products and product packaging families.
- Analyze the perfect product-specific adjustment for each Haffmans number.

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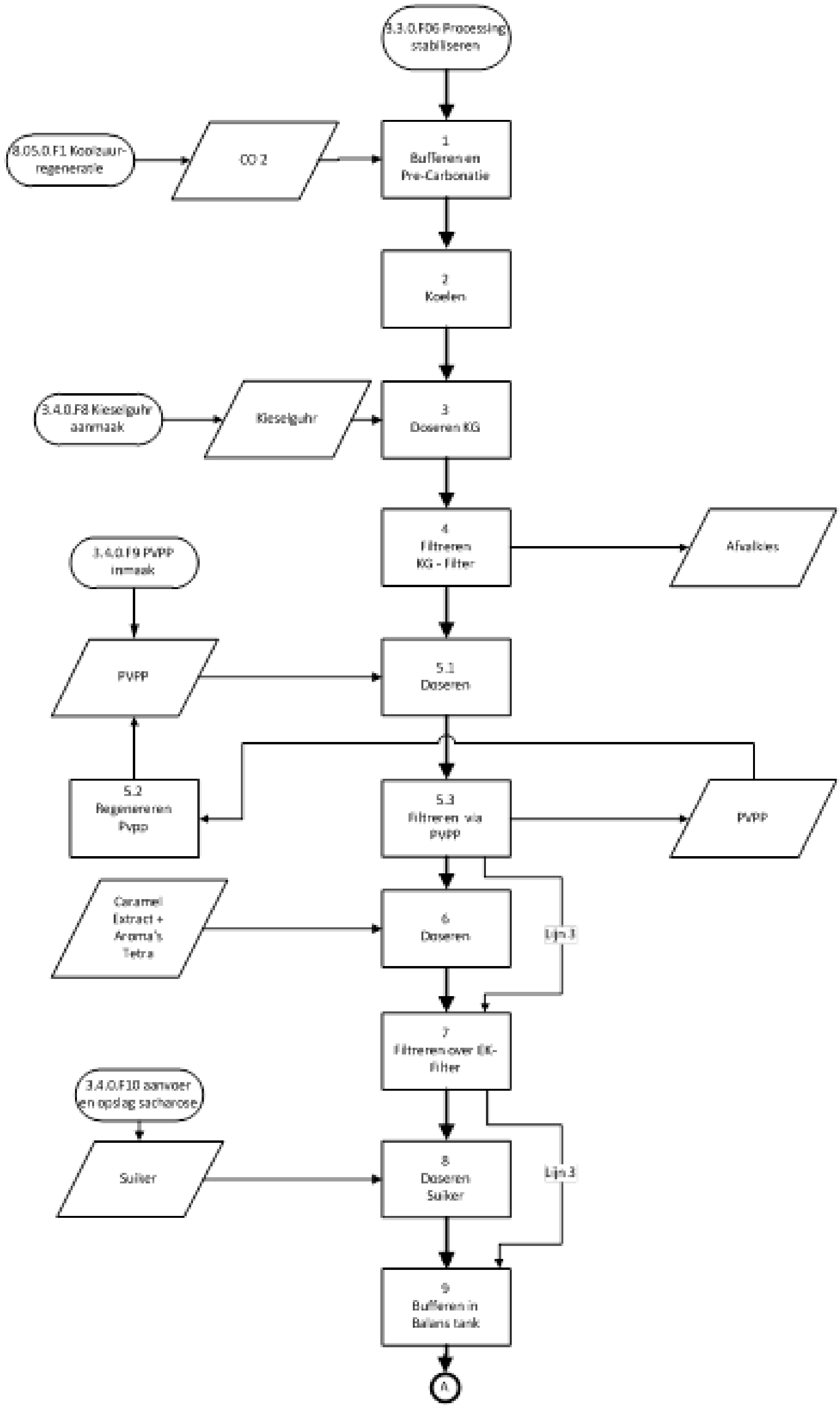
APPENDIX

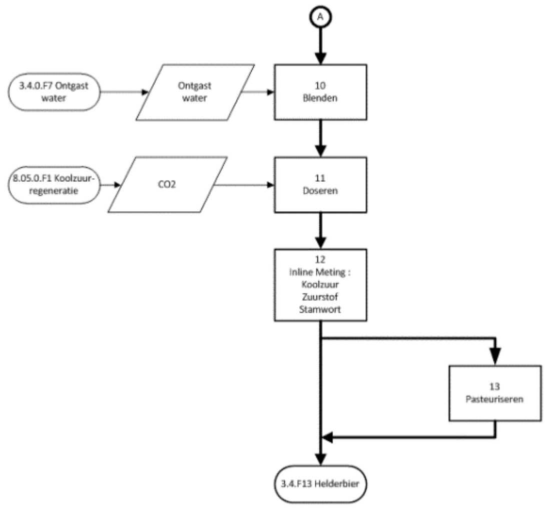
A. STAKEHOLDER ANALYSIS

Stakeholder	Stake in the project	Impact	What do we need from them?	Perceived attitude/risk	Stakeholder Management Strategy
Technicians/ Mechanics	The technicians, also called mechanics, are the contact person for solving the actual problems within the brewing process flow. If a hatch does not close, they are the persons to call.	Medium	Explanation over the implementation, maintenance and regulation of the *Anton Paar*	Are not yet informed about the research project.	Involvement in briefing sessions and collaboration.
Quality Assurance	The analysts are the ones who test the samples and give the values to the operators.	Medium	Values of extra measurements.	More work for them.	Involvement in briefing sessions and collaboration.
Operators	The operators are the people who are responsible for the process and the automation system. They are also the ones who have to be cautious, take samples and readjust the automation system while the filtration process is going on.	High	Measurements of *Anton Paar*, explanation and help with the automation system *Brewmaxx*.	Close collaboration could mean they can do less work.	Close collaboration, involvement in project and adjustments.
Project Manager	The project managers are the supervisors of the operators.	Low	-	Team gets more tasks from me.	Involvement in Project. Regular updating and meeting with project managers and managers.
Technical Brewer	Technical brewers are in charge of the whole process of brewing and filtering beer. Their key aim is to ensure the quality and consistency of the product.	Low	Explanations of the process and quality of the beer.	-	Involvement in Project. Regular updating.

Manager 'Brewing'	The managers from the department 'Brewing' are the commissioners of this project. They have noticed the problem within their department and want to know if there are possible bottlenecks within the production process of *Grolsch*.	Medium	Accessibility to information. Time from the team.	-	Involvement in Project. Regular updating and meeting with project managers and managers.

B. FLOW CHART FILTRATION





C. FILTER CAPACITY AND VOLUME

D. CALCULATION OF FLUCTUATION PERIOD

E. STATISTICAL SUMMARY BATCH SIZES

F. HAFFMANS NUMBERS

G. CONTACT INFORMATION