Influence of Hydrostatic High Pressure on the Filterability of Beer

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Paper presented at the World Brewing Congress 2000, Orlando, Florida, USA.

ABSTRACT

The use of high pressure in the food industry was introduced by a Japanese industry consortium in 1989. The first intention was to stabilize products without thermal treatment. But there are a lot of other possibilities of using this technology. For example, for wine or beer production.

We started screening the whole brewing processes to find interesting possibilities for the use of high pressure. The samples were treated at 300, 500, 700 MPa for 5 minutes. The measurements resulted in a significant reduction of filtration duration on the samples treated with 300 and 500 MPa, also with increasing volumes. The filterability of the beer samples at these pressures is very close to the filterability of water.

But now arises a new question: Which parameters are responsible for the better filterability? Particle-size, nitrogen-content and polyphenols stay constant. Relative to these results, it is possible to conclude that the improvement of the filterability due to the high pressure treatment affects the behavior of β-glucans or β-glucan gels.

The high pressure treatment not only improves beer filterability, it is also possible to induce the isomerization of α-acids and to improve the microbiological and colloidal stability of beer without any thermal influence.

Keywords: hydrostatic high pressure, beer filterability, β-glucan, particle-size, nitrogen, polyphenols

SINTÉSIS

El uso de alta presión en la industria de los alimentos fue introducido por un consorcio industrial japonés en 1989. Su primera intención fue la de estabilizar los productos sin tratamiento térmico. Pero hay muchas otras posibilidades para el uso de esta tecnología. Por ejemplo, la producción de vino o de cerveza.

Nosotros empezamos a supervisar todo el proceso de la elaboración de la cerveza, para encontrar posibilidades del uso de alta presión. Las muestras se trataron a 300, 500, 700 MPa por 5 minutos. Las medidas resultaron en una reducción significativa de la duración de filtración en las muestras tratadas con 300 y 500 MPa, así como un incremento de volumen. La filtración de las muestras de cerveza a estas presiones es muy cercana a la filtración del agua.

Pero ahora hay una nueva pregunta: ¿Qué parámetros son responsables de la mejor filtración? El tamaño de las partículas, el contenido de nitrógeno y los polifenoles se mantuvieron constantes. Tomando en cuenta estos resultados, es posible concluir que la mejoría de la filtración debido al tratamiento de alta presión no depende del comportamiento de los β-glucanos o geles β-glucanos.

Pero el tratamiento de alta presión no solo tiene avances en la mejora de la filtración, es también posible el inducir la isomerización de ácidos alfa y el mejorar la estabilidad microbiológica y coloidal de la cerveza sin influencia térmica.

INTRODUCTION

High pressure technology isn’t a new development of some Japanese companies. It has been used already for about 110 years. The first high pressure plant was developed by Hite in the 19th century. He tried to sterilize milk. In 1913, Bridgeman made determinations about the physical properties of water and proteins under the influence of high pressure. But since then nothing further has happened. In 1989, a Japanese consortium of 12 members was founded. Their aim was to develop high-pressure-treated food. The first products, sold in 1991: were fruit jams, purees and grapefruit juice. In 1996, the first product in Europe was also high-pressure-treated fruit juice sold in France.
and in 1998, a high-pressure-treated avocado dip was sold in the USA. Now the Coca-Cola Company wants to treat their orange juice with high pressure.

After this short history I would like to define the range of high pressure. For all brewers, a bunging pressure of 1 MPa (10 bars) is much too high pressure for us. For the extraction of some flavors you need about 80 MPa, and they also consider this to be high pressure. Think about diving; no human being is able to reach the deepest point of the oceans because there is a pressure of about 100 MPa, also high pressure. But these are very low pressures compared to high pressure treatment in the food industry. The different applications are mostly realized at pressures between 200 and 600 MPa.

**EXPERIMENTAL**

There are generally two ways of generating high pressure. First the indirect pressure generation: there is an external pressure transmitter and the generated high pressure attained through pipes to the high pressure vessel. The product is located in the pressure vessel. The advantage of this system is that you can lock one vessel and work with a second, besides you can work with more vessels in parallel. The generation of high pressure belongs to the transmission ratio of the pressure transmitter. When working with air pressure of about 0.6 MPa, a high transmission ratio is needed. For example, if you want to create 600 MPa you need a transmission ratio of 1000. This transmission ratio is defined as the ratio of the two planes, the bigger one on the low pressure side, the smaller one on the high pressure side. Force is pressure multiplied with plane, the force stays constant over the transmitter. Pressure is force divided through plane. We have a smaller plane, therefore, the pressure becomes higher. When you use a hydraulic aggregate for generating the pre-pressure, the transmission ratio can be less.

The second possibility is to create high pressure directly in the vessel. This method is based on the same principle but it is only practical for small experimental plants. Meanwhile the influences of high pressure on food ingredients are very well known. Carbohydrates show gel formation under pressure but there are enormous differences between different starch types. Maize starch, for example, gelatinizes at 400 MPa, potato starch not until 800 MPa.

Lipids partly oxidize and because of their high compressibility, it is possible that there are local temperature peaks which do not allow a homogenous treatment.

The inactivation of microorganisms depends on their shape and their pressure resistance. It is very difficult to inactivate spores, as they need a kind of tyndalization. Vegetal cells are very pressure sensitive especially in the state of increase and propagation. Most high pressure applications in the food industry are for sterilization, especially in products with a low pH value.

The content of vitamins when thermally treated is very interesting. In apple juice, for example, there is a loss of about 50%; with high pressure the loss is only 10%! For minerals and pigments there is nearly no influence, only at high fat contents there is perhaps a loss of color. Jams and juices keep their original color.

Gases, for example, carbonic acid in lemonade, have synergetic effects in inactivating microorganisms because they are in a hypercritical state at high pressure and thus, transitions from gas to liquid and vice versa can damage microorganisms. The most important food ingredient is water and water has some very special properties under pressure. Water is fluid at negative temperatures at a pressure up to 700 MPa; at high pressures water becomes solid. It is, for example, possible to take a frozen product, defrost it under pressure, mix it with some ingredients and freeze it again during decompression. Because of the different states of ice and the different configurations, it is possible to create different surfaces due to the particle size of the ice.

Proteins show different behavior under pressure. The quaternary structure folds at about 200 MPa, the tertiary structure folds reversibly, and the covalent ties of the primary structure are hardly influenced. Hydrophobic reciprocal reactions can be influenced, so it is possible to deform the active center of enzymes; they change their specificity or lose their activity. The proteins can also be deformed in such a way that they cannot be recognized by the enzymes anymore. Covalent ties can not be influenced, so the primary structure of an enzyme or a protein won’t be deformed.

Very interestingly is the behavior of proteins due to their denaturation. By using pressure, it is possible to avoid denaturation, which will happen under atmospheric conditions. On the other hand, a protein is able to denature at temperatures below atmospheric values. Proteins have very different denaturation diagrams, so it may be practicable to segregate proteins with pressure and temperature.

But all these reactions depend on one point: Are they catalyzed under pressure? Henry Le Chatelier postulated that pressure supports reactions when the volume of the product is smaller than the volume of both reactants. If these conditions are fulfilled, a spontaneous reaction course will occur, the reaction is catalyzed by the pressure.

Temperature and pressure influence the kinetic of chemical reactions. The reason for this is the change of the chemical
potential of the substances. The position of the equilibrium depends on the change of the activation volume. Under pressure, the equilibrium is closer to the most compact state. If the pressure-induced volume decrease is bigger than the activation volume, the reaction starts and the whole volume decrease of the reaction will be reached. The activation volume is smaller than the reaction volume.

In breweries there are many possible applications for high-pressure treatment. The idea to use high pressure in the brewery comes from juice stabilization. So the first steps in using high pressure in the brewery have been to improve the stability of beer without thermal influence. As a result of testing, we determined that the potential for turbidity increase is reduced and colloidal stability is improved. Microbiological stability and foam stability were comparable. Only the hop flavor was influenced; the bitterness was milder. After this successful beginning we did screening in other parts of the brewery. We determined a faster saccharification in the mash vessel; the a-amylase works faster and shows a better temperature resistance. The protein fractions in the mash, also show very different contents; specifically, the dipeptidases seemed to be inactivated.

At wort boiling, we determined that it is possible to induce the isomerization of α-acids by high pressure. The mixing of the hop ingredients was worse because of the lack of flow under pressure. However, the percentual result of the isomerization was very good. Because of these experiences, the change in protein structures and the influence on carbohydrates, we recognized one important effect: all these substances strongly influence the filterability of beer. So we began to determine the influence of high pressure on beer filterability and our first results were very encouraging.

The first measurements were carried out with beer which had no problems during the filtration; we wanted to see if it were possible to influence filterability. These measurements were done on a laboratory filter with a cellulose sheet. Determination of the particle size, the proteins and polyphenols were performed as well. The analyses were carried out according to the instruction rules of MEBAK. After that we used beer with many filtration problems; the measurements in this case were done with a modified Raible-Test, with kieselguhr. The β-glucan gel was analyzed with a β-glucan gel analyzer.

The high pressure treatment was performed in a high pressure plant with a volume of 1.3 liters, the beer was filled in PET bottles, the pressure increase rate was 200 MPa per minute.

RESULTS AND DISCUSSION

Our first measurement did take place on a laboratory filter with a cellulose sheet, (void width 25 μm). We filtered 30 and 40 ml of the sample; for comparison we performed one test run with water. The result is obvious: at 300 MPa the filterability of the beer is nearly comparable to water. At high pressures, the filterability deteriorates again. This is the reason why we stopped testing on the 700 MPa sample. This area is generally not very interesting for industrial applications because the technical effort will be very high. If we regard the different volumes which were filtered, we recognize that filtration time is proportional to the volume. After this astonishing first result we tried to find out which reasons are responsible for this tremendous increase in filterability.

To determine the influence of particle size, we centrifuged the high-pressure-treated beer samples at different settings and measured the absorption in the protrusion. The less absorption we determined in the protrusion, the bigger the particles became during high pressure treatment. At 700 MPa the particles became smaller and the absorption increased. Another reason for surrendering these samples. At 500 MPa there is a slight decrease in the particle size, but at 300 MPa there is no difference. If we survey the last two slides, there are two logical conclusions. First, at 700 MPa the particles become smaller and the voids in the cellulose sheet will be closed by them, and filterability becomes worse. Second at 500 MPa the particles are a little smaller than with 300 MPa or the untreated sample, but the filterability is better than in the untreated one. So the particle size has a definite influence; but there are other reasons for the better filterability. At 300 MPa the particle size is the same as in the untreated sample but the filterability is better, this will support the conclusion I made before.

The protein content increases at 100 MPa, but the interesting samples at 300 and 500 MPa show again nearly the same amount as the untreated sample, especially in the filtered sample. After filtration, the 500 MPa sample has a lower protein content than the untreated and the 300 MPa treated samples. It is possible that the middle molecular protein denatures under pressure to high molecular proteins and they will be retarded by the filter. The polyphenols and anthocyanogens show only a very small increase with increasing pressure, perhaps due to a splitting of the protein – polyphenol complexes. But this influence cannot explain the better filterability. Concluding, we can remark that there is only a difference in the filterability and the particle size. The protein and the polyphenol content stays nearly constant. So there is the question, why does the filterability improve? To determine this we used beer with a high content of β-glucan gel because it is the primary reason for having filtration problems.

In Figure 2 we can see that the β-glucan gel content of the untreated beer is about 19 mg/L, and the high pressure treated

![FIGURE 2](https://example.com/figure2.png)

Beta-glucan gel after high pressure treatment
samples show no detectable \( \beta \)-glucan gel content (the detection limit is 10 mg/L). It seems that the \( \beta \)-glucan gel is cracked. The bonds between the filaments will be opened and the bound water will be released. This conclusion is very likely because the volume of the products is smaller than the volume of the gel and the bonds can be easily cracked by high pressure.

We then wanted to see if these theoretical results would work in a more practical application. The high-pressure-treated samples were analyzed with the modified Raible-Test. As you can see in Figure 3, it is possible to improve the filterability of beer using high pressure even with kieselguhr filtration. The specific filterability of the untreated beer was at 3.6; after the high-pressure treatment the values increased to 4.0 at 300 MPa and even 5.1 at 500 MPa. The critical range of the specific filterability is at 4.0, so it is obvious that the sample treated with 500 MPa will achieve an enormous improvement of the filterability.

These results must be subjected to several far-reaching tests to determine the exact reactions under high pressure and to prove these results. These first results are very promising and it will be very interesting what high pressure does particularly with the carbohydrates, the proteins and the polyphenols of the beer.

**ACKNOWLEDGEMENTS**

This project was supported by the “Wissenschaftsförderung der Deutschen Brauindustrie.”

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![Graph showing filterability after high pressure treatment with kieselguhr filtration (modified Raible-Test).](image)

**CONCLUSION**

The conclusions of this work are quite clear. It is obvious that high-pressure improves the filterability of beer. It doesn’t matter if you use a kieselguhr or sheet filter. It is also possible to crack \( \beta \)-glucan gel.

But there is one important difference. If you treat a beer with a good filterability and nearly no \( \beta \)-glucan gel, you can improve the filterability by using a pressure of 300 MPa, otherwise, if you treat a beer with \( \beta \)-glucan gel content of, for example, 19 mg/L you get the best results with a pressure of 500 MPa. So it is obvious that different mechanisms affect this result. On the one hand, there can be certain influence on the proteins, and on the other hand, there can be the cracking of \( \beta \)-glucan gel by high pressure.