

## ENZYME SOLUTIONS TO SUPPORT SUSTAINABLE BREWING AND DISTILLING

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### ABSTRACT

The recent price increase for raw materials and energy is forcing industries toward process optimisations with a focus on alternative raw materials, energy and water savings. The discussion about more sustainable production methods intensifies and the first carbon footprint of beer has appeared.

Life Cycle Assessment (LCA) is a tool and a method that enables quantification of environmental impacts of new technologies. LCA addresses all processes in the product chain - from raw material extraction through production and use to final disposal.

Enzymes are efficient biological catalysts and can increase efficiency and yield of a wide range of processes in society but with less impact on nature.

One way to sustainably produce beer and at lower costs, is by substituting imported malt with locally grown cereals. With recent developments in enzymes (Cerezyme<sup>®</sup>) it is possible to replace malt up to 100% with sorghum and also barley. The throughputs and efficiencies of these processes using enzymes are very high. The produced beers are of acceptable quality and have a lower carbon footprint.

Another way is to save energy and water, by processing at a higher dry substance (DS) level, using suitable enzymes.

This paper will present results with enzymes and preliminary LCA findings.

**Keywords:** *life cycle assessment, enzymes, barley and sorghum brewing, high gravity brewing and fermentation, high % DS, energy and water savings*

### INTRODUCTION

#### Why sustainability?

In 2005 the World Business Council for Sustainable Development noted that the human activity over the past 50 years had changed nature more rapidly and extensively than ever before, largely in order to meet rapidly growing demands for food, fresh water, timber, fiber and fuel.

Sustainability has long been at the forefront of the brewing industry and Sapporo Breweries Ltd, Hokkaido, will start test sales of beer with 'carbon footprint' labels on cans in a bid to contribute to efforts to combat global warming<sup>1</sup>. The labels will show the amount of carbon dioxide emitted during the production process of each can, ranging from the operation of agricultural machinery in barley and hop production, to recycling. The labels will be on Black Label beer that will be sold at the normal price.

### **Sustainability by using enzymes**

The industrial revolution has been very successful in providing an incredible amount of goods but in many places, it has been at great cost to nature and natural resources. There is need for accelerated economic growth to meet the needs of a growing world population but which have less impact on nature.

Enzymes are efficient biological catalysts and can increase yield of a wide range of processes. With enzymatic solutions it is possible to produce more with less and contribute to the decoupling of economic growth and use of nature.

### **What is a Life Cycle Assessment (LCA)?**

LCA is a method that enables the quantification of environmental impacts of new technology by addressing all processes in the product chain from raw material extraction, production and use, to the final disposal.

The four environmental indicators are: global warming, acidification, nutrient enrichment and smog formation, also the consumption of resources like fossil energy, minerals and land must be taken into consideration.

LCA is used to compare environmental impacts of two or more alternative processes providing the same benefits to the use and enabling an evaluation to be made on conventional processes vs. enzyme assisted processes.

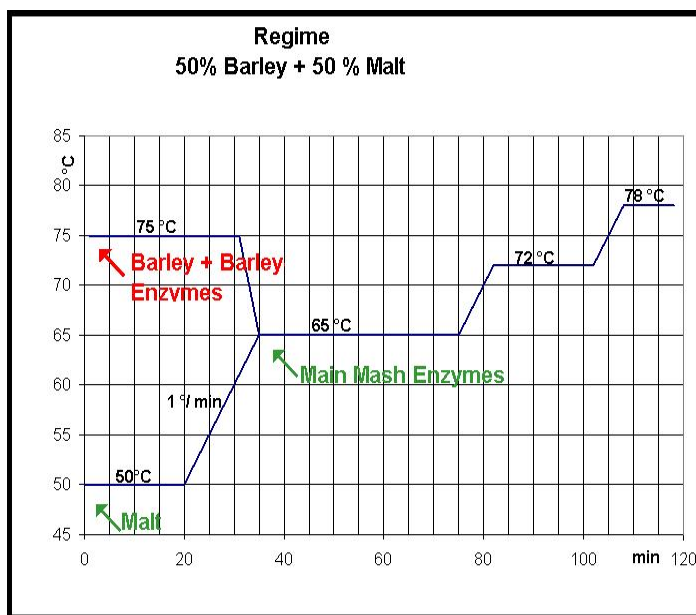
## **ENZYME SOLUTIONS FOR SUSTAINABLE BREWING**

### **Use of 50% unmalted barley**

#### ***Process options (Fig. 1)***

There are several options on how to substitute 50% malt with barley. One way is to process the barley together with the malt in an infusion mashing.

Another way is to split the barley mash and process part of it with the other adjuncts (rice, maize) in the adjunct cooker and then the remaining barley together with the malt mash. A further option is to process 50% barley in the adjunct cooker at optimally 70°-75°C for 30 minutes and then mix with the malt mash for saccharification and further processing.



**Fig. 1 Mashing diagram for processing 50% barley in the adjunct cooker**

## Use of 100% unmalted barley

### Process options

Using up to 100% unmalted barley can be done with an infusion process and by the use of external enzymes. In order for this to succeed, the requirements are that it:

- fit into a standard production slot
- be worked with standard brewing equipment
- has the ability to work with high gravity and adjuncts
- is independent of barley variety and source
- has the same yield and yeast performance as standard beer
- is maltose based beer
- has no beer faults
- has simple enzyme usage.

### LCA 'light' for a 100% barley beer: Preliminary results

The LCA quantifies the saved and used flows. In the case of the 100% barley beer all the malt has been saved but 20% more barley was required. Further there was a higher consumption of electricity for the milling of barley compared to malt. 4.6Wh/kg barley extra was used for the calculation. The enzyme consumption calculated was 40g/hl beer.

The results show that, per hl beer (12°P) 16.7kg CO<sub>2</sub> eq. can be avoided and 13.4kg CO<sub>2</sub> eq. is induced; resulting in a net reduction of Greenhouse Gas (GHG) emission of 3.3kg CO<sub>2</sub> eq. per hl beer, when 100% malt is substituted. The 3.3kg CO<sub>2</sub> is the average of a range of 2-4kg CO<sub>2</sub> depending on the energy efficiency of the malthouse. For a 50% substitution the data is 1.5kg CO<sub>2</sub> eq. per hl with a range of 1-2 kg CO<sub>2</sub>/hl beer. Interestingly the environmental load of the enzyme(s) production and the enzyme dosage(s) do not significantly affect the result. The induced value for the enzyme

production is only 0.6kg CO<sub>2</sub> eq./hl beer. The grade of barley does have a minor impact. The main influence on the result is the energy efficiency of the malthouse.

### Comments

- Reductions effected of 3.3 kg CO<sub>2</sub> eq. per hl beer (12°P) corresponding to just over 200 kg CO<sub>2</sub> eq. per ton of malt substituted with barley;
- GHG reductions effected by substituting 18 ton of malt is equivalent to the annual GHG emissions from 1 passenger car (when driving 20 000 km/year);
- 1.8 Mio to malt (around 10% of global production) substitution by barley would result in GHG reduction in the magnitude of the emissions of 1 Mio cars;
- No clear conclusions were drawn for other environmental impact categories;
- For a full LCA more information is required regarding
  - avoided international transport (due to shorter supply chain from locally grown barley)
  - possible changes in barley production (less N fertiliser, lower yields etc.)
  - increased maintenance of milling machinery
  - the implications for the use of spent grains.

### Use of unmalted sorghum

#### Optimal process (Fig. 2)

The use of malted and unmalted sorghum for beer production in Africa has been known for several years. What is relatively new is the development and optimisation of a simple, but very efficient, process using up to 100% unmalted sorghum and only 2 enzyme preparations: Cerezyme<sup>®</sup> Sorghum in the cereal cooker and Fungamyl<sup>®</sup> BrewQ in the mash tun.

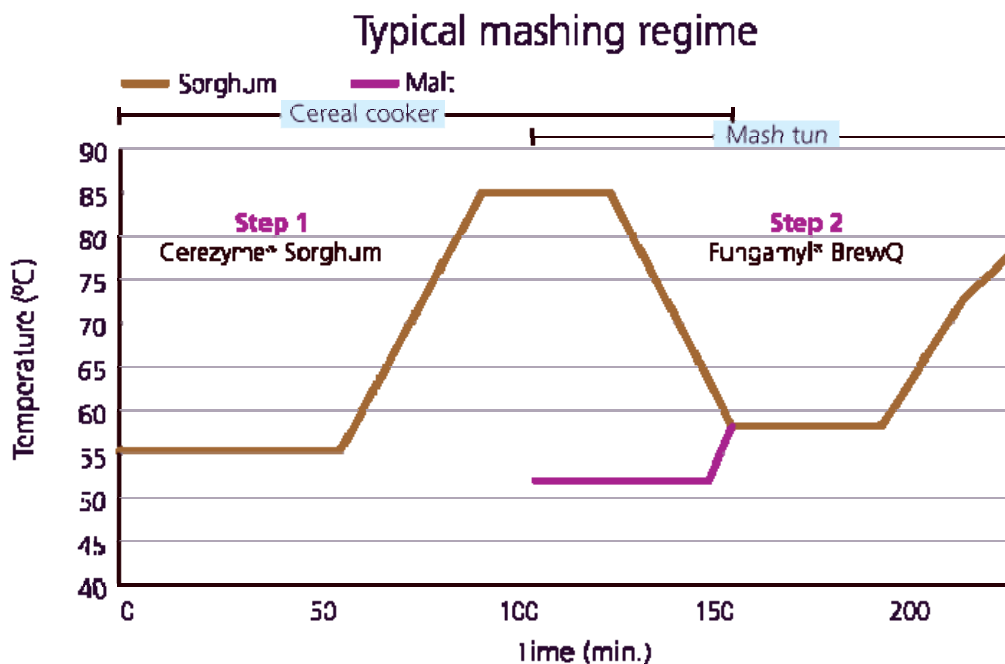


Fig. 2 Typical mashing diagram for up to 100% unmalted sorghum

### **Benefits for the brewery**

- Cost savings by using unmalted sorghum;
- High brewing efficiency in processing time, filtration, extract;
  - increased throughput (1-2 more brews in some breweries)
  - high extract yield - brewers get the most out of sorghum; low alpha-glucan levels
  - No processing problems; no clogging of mash filter;
- Flexibility in raw material composition and optimised adjunct costs;
  - unmalted barley can be mixed into the mash bill (together with sorghum) without any processing problems;
- Demonstrating social responsibility by supporting local farmers.

### **Expected sustainability benefits from a LCA point of view**

- CO<sub>2</sub> eq. reductions per hl beer are similar but probably even higher compared to unmalted barley;
- Lower resource requirements (water, land, fertilisers) for sorghum compared to barley:
  - for instance sweet sorghum has only a 'climate load' of 0.3kg CO<sub>2</sub> eq./kg grain compared to barley with 0.5-0.9kg CO<sub>2</sub>
  - less sorghum is needed to substitute malt compared to barley;
- Use of locally grown sorghum with less transportation;
- A LCA light of full LCA still needs to be done for brewing with 100% unmalted sorghum.

### **Processing at high or very high gravities in distilling and brewing**

#### **High or Very High Gravity Fermentation (HGF) in distilling**

One way to save energy is to process, cook and ferment at a higher Dry Substance (DS) level by using enzymes and less water – also known as High Gravity Fermentation. HGF means an increased Dry Substance (DS) in the mash and a reduced usage of water. For instance at 15%DS 5m<sup>3</sup> of water is used per ton grain whereas at 35%DS only 1.5m<sup>3</sup> water is used. The grain-water-ratio drops in this case from 1:5 to 1:1.5

Further with HGF, an increased grain throughput can be realised with less water usage and using the same tank capacity. At 30-35%DS the grain throughput is double or more compared to 15%DS.

Besides water savings substantial energy savings can be realised when processing at higher DS and running HGF. It takes only one third of the energy to heat up 1kg of grain compared to heating of 1kg of water<sup>3</sup>. Therefore the higher the dry substance in the mash the less water needs to be heated and the less overall energy is expended. Further energy savings can be realised after fermentation as less water needs to be evaporated during distilling and also there will be less energy required for the drying of the DDG (Dried Distillers' Grains).

Today corn is processed in the USA at 30-35%DS using a state-of-the-art and modern alfa-amylases for liquefaction, which have also the ability to reduce the mash viscosity.

However when using rye, wheat, barley or triticale, the massive increase in viscosity is one of the drawbacks associated with running at a higher dry substance level.

Wheat, barley and rye show a much higher cell wall material content compared to corn (**Fig. 3**). The higher cell wall material content is the reason for the higher viscosities of these grains. Among these cell wall materials, mainly arabino-xylans and beta-glucans are found. A closer look at the compositions of the cell wall component show that wheat and rye are high in soluble pentosans, mainly arabino-xylans, whereas barley has high soluble beta-glucan content. Corn (maize) has little soluble pentosans and no soluble glucans. This is the main reason, why high viscosity in corn is less, or not at all, problematic.

The high Non Starch Polysaccharides (%NSP) content in rye, barley and wheat needs to be degraded by suitable enzymes in order to get low viscosities and achieve high %DS and HGF<sup>4</sup>.

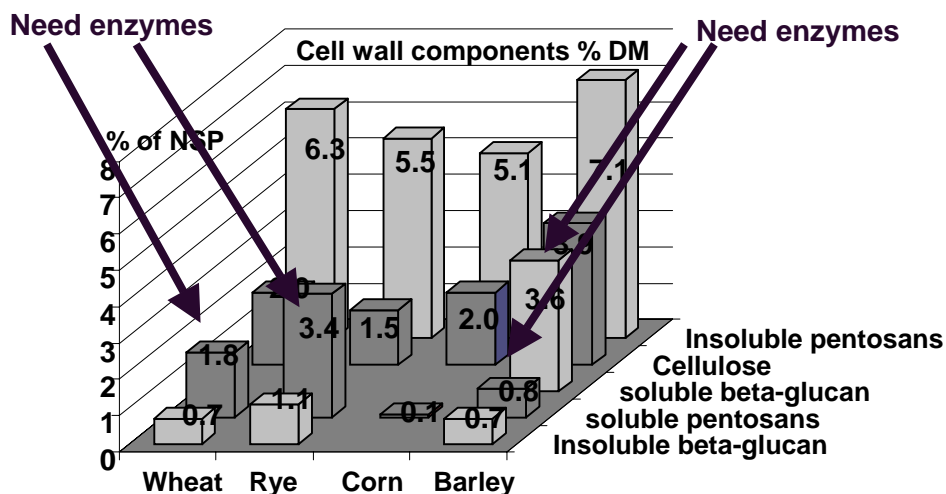


Fig. 3 Cell wall components in grains

The new development in this sector has led to an enzyme product (Viscoferm<sup>®</sup>), which contains, among others, a unique endo-xylanase of the GH 10 family. The GH 10 endo-xylanase is able to cleave and degrade arabino-xylans also when the xylose is linked with arabinose or in the case of xylo-glucan also when linked to glucose. Xylanases of the GH 11 family, however, are only able to cleave arabino-xylan, when the xylose is not linked to arabinose or another molecule. The advantage of this endo-xylanase GH 10 is that it can attack the arabino-xylan at any point and leading to a much lower mash viscosity.

### Effect of DS on viscosity

**Fig. 4** shows the enormous impact of increasing DS 28%, 30%, 32%, 36% on viscosity of rye mash and enzyme performances over time. The enzyme treatment leads to viscosity reductions of less than 20% of the original viscosity in less than 60 minutes. In this way the rye mash slurries, as high as 36%, can be pumped and processed.

### Industrial results and experience

The enzyme has been added prior to liquefaction as usual to the slurry mix tank. A 20-30 minutes holding at 50-55°C is standard, but there is potential to improve the set-up.

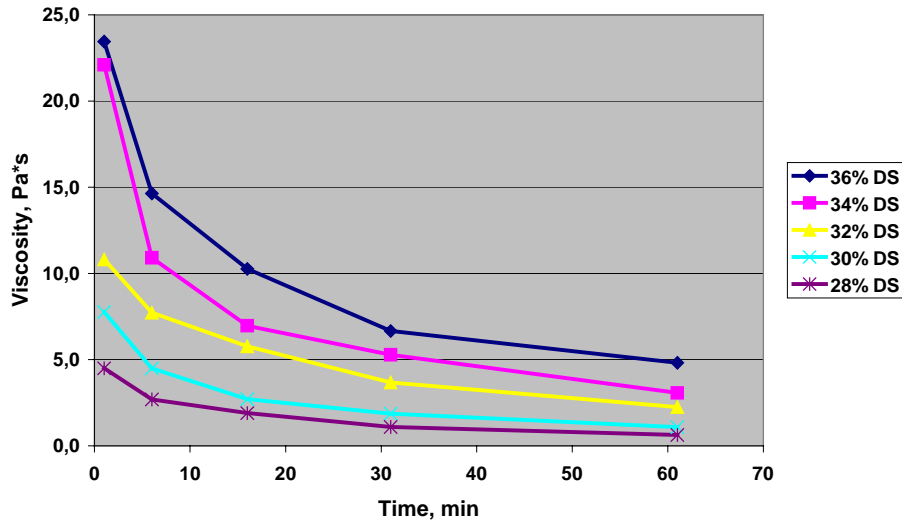


Fig. 4 Viscosity reduction with Viscoferm enzyme on 100% rye

### Example 1: 100 % rye (Table I)

Distillery A got maximal 7.5% alcohol, when not using any viscosity reducing enzyme. With a 2<sup>nd</sup> generation viscosity reduction enzyme (VRE) the obtained alcohol yield was just above 10%. Using the new enzyme the viscosity could further be reduced and %DS maximised. The maximum alcohol output was 14.6% using a high alcohol tolerant yeast strain.

TABLE I Industrial experience on 100% rye			
100% RYE	Control	Viscosity Reduction Enzyme (VRE) 2 <sup>nd</sup> gen.	Viscoferm <sup>®</sup>
Enzyme dosage	No VRE	0.15 kg/ton rye	0.15 kg/ton rye
DS achieved	15 - 18.7%	25.0%	36.5%
Alcohol content in mash (v/v)	6 - 7.5%	10.0%	14.6% Special yeast used
Mash water use per 1 m3 alcohol	12.5 m3	7.2 m3	4.0 m3
Energy savings	Benchmark	25% steam reduction	> 50% steam reduction

The mash water could be reduced from 12.5 m<sup>3</sup> with no VRE use down to 4.0 m<sup>3</sup> per 1.0 m<sup>3</sup> alcohol. Calculated per ton rye the mash water use could be reduced from 4.4 m<sup>3</sup> with no VRE use, down to 1.4 m<sup>3</sup>.

The energy savings were a 50% reduction of steam for cooking and distillation.

**Example 2: 100% wheat (Table II)**

Distillery B used the best 2<sup>nd</sup> generation VRE on the market and could get maximal 12% alcohol content. Using Viscoferm the DS could further be increased and alcohol output was over 14.5%. A yeast strain with high alcohol tolerance was used during fermentation and special attention has been given to have enough yeast nutrients available.

The steam usage could be further reduced by 25% compared to a 2nd generation VRE use but over 50% compared to no viscosity reducing enzyme.

TABLE II Industrial experience on 100% wheat			
100% Wheat	Control	VRE 2 <sup>nd</sup> gen.	Viscoferm®
Enzyme dosage	No VRE	0.10 l/t grain	0.10 l/t grain
Alcohol (v/v)	8 - 9%	10 - 12%	> 14.5% Special yeast used
% DS achieved	18.9 – 21.3%	23.7 – 28.5%	34.3%
Energy savings	Benchmark	20-25% steam reduction	> 50% steam reduction
Capacity increase	Control	+ 30%	> 70%

**Example 3: 100% Wheat**

The test results in distillery C were as follows:

- Alcohol increase from 8% to 12.5%. The limiting factors were not the viscosity but the special distillation columns with plates, which do not allow distilling beer mashes over 12.5% alcohol;
- One of the production lines could be closed as the other line’s capacity could be doubled;
- The energy savings (steam and electricity) were €2.68/ton wheat based on a very low steam price of €4/ton in this region, 2 years ago. The energy savings split was €1.51 for steam and €1.17 for electricity;
- Using more actual costs for steam of €20/ton or even €40/ton, the energy savings in this case would have been over €8 per €16 /ton wheat;
- The water savings per ton wheat were 1.875m<sup>3</sup> and the steam savings were 0.378 ton.

**Conclusions on boosting HGF in distilling**

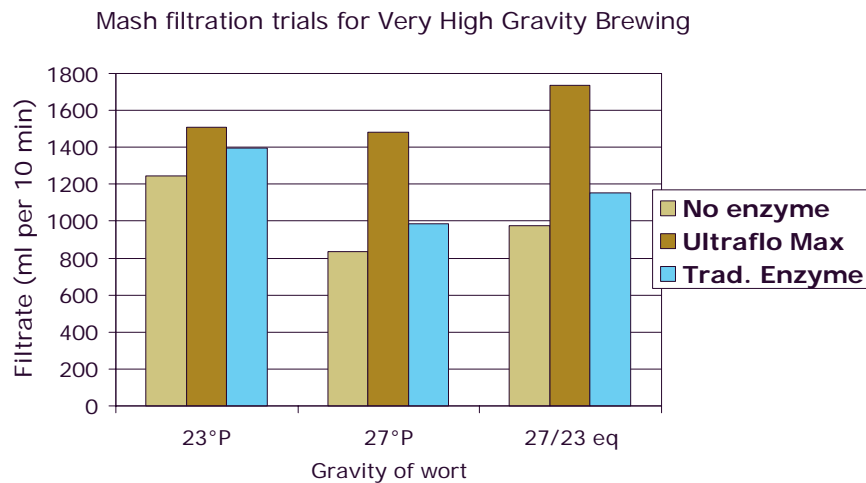
- The development of a new enzyme product has made it feasible to drastically reduce mash viscosities in challenging raw materials such as rye, barley, wheat and triticale.
- With the obtained low viscosities, it is feasible to process these raw materials at over 30%DS and have 14% alcohol.
- 25-30% of the total energy and water can be saved compared to processing at 15-20% DS.
- Stillage waste can be reduced by increased recycling.

- Process improvements can be achieved with no added investment or only slight adjustments.
- The enzymatic pre-treatment contributes to a more sustainable production process by using less energy and water.
- High and further rising energy prices will continue to make the concept even more attractive.

### Boosting High Gravity Brewing (HGB)

There has been a recent similar development with viscosity enzymes in the brewing industry. With the introduction of Novozymes unique brewing filtration enzyme (Ultraflo<sup>®</sup> Max), which contains also the unique endo-xylanase of the GH 10 family, it is possible to improve and boost current applications. One of the obvious applications is to use this enzyme for boosting HGB.

**Fig. 5** shows the results on lab mash filtration for very HGB: 23°P vs. 27°P. The tests were done on very well modified malt of European origin and using a lab mash filter, type MEURA. The obtained filtrates (ml/10 min) show that the new enzyme can boost the filtration rates e.g. at 27°P is the filtrate volume with Ultraflo Max 78% higher than the control with no enzyme and still 50% higher compared to traditionally used brewing filtration enzymes. Calculated on the same sugar concentration is the throughput at 27°P even higher than at 23°P when using the new enzyme.



**Fig. 5** Mash filtration trials for very HGB with new enzyme

### Outlook

Future enzyme support for sustainable brewing could be energy production from spent grains and could make an enzyme based colloidal beer stabilisation feasible.

## SUMMARY and CONCLUSIONS

- Enzymes are suitable tools to enable and support more sustainable processes across industries.
- LCA is a method to measure environmental impact of processes and compare technologies.
- Using unmalted barley plus enzymes instead of malt, show preliminary LCA light results in GHG reductions of
  - 3kg CO<sub>2</sub> eq. per hl beer when 100% substituted;
  - and 1.5kg CO<sub>2</sub> eq. per hl beer at 50% substitution rate.
- It is expected that using unmalted sorghum plus enzymes instead of malt, would result in similar or even higher CO<sub>2</sub> eq. reduction compared to barley. LCA light is needed for conclusion.
- Processing at higher gravities in distilling and brewing leads to significant savings in energy and water at increased output.
- Future enzyme applications to support more sustainable brewing could include: kieselguhr free filtration, energy production with spent grains or only enzyme based colloidal beer stabilisation;

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