Institution: Heriot-Watt University

Unit of Assessment: A06: Agriculture, Veterinary and Food Science

Title of case study: Better Brewing Through High Gravity Fermentation.

1. Summary of the impact (indicative maximum 100 words)

In High Gravity (HG) brewing the substrate (the wort[§]) fermented by the yeast is concentrated from a traditional value of about 12% solids to concentrations of upwards of 20%. Research (1993-2008) by Graham's Stewart's team at Heriot-Watt, into the process of brewing beer and distilling spirits in a more cost effective and quality enhanced manner led to substantial improvements in the HG brewing process, now used worldwide. This allows up to 50% more beer to be made at the same plant and reduces distillation costs. In both industries HG-wort production has allowed very substantial savings (>£555 million) in capital expansion costs.

§The substrate produced by the mashing of malt and grains - primarily consisting of fermentable sugars.

2. Underpinning research (indicative maximum 500 words)

Professor Stewart and his research group were active from 1994 to 2012, producing more than 50 publications. The majority of these publications investigated the high gravity brewing process (for reviews see Stewart, 2009; Stewart and Murray, 2012). This process of creating a HG-wort is relatively simple and can be done by either concentrated brewing, or more commonly, by adding sugar syrups to a normal wort (of ~12^{o}P or 12% solids) to reach 15 to 21^{o}P. However, this high osmotic substrate has negative effects on: 1) beer foam stability, 2) yeast fermentation performance and 3) final beer flavour. From 1993 to 2008, Professor Stewart's team pioneered research aimed at solving all three issues. He has been honoured by the Master Brewers of Americas, the American Society of Brewing Chemists and the Institute of Brewing and Distilling primarily for his work on understanding and providing industrial solutions to these problems.

Beer Foam Stability - In addressing the problem of low foam stability caused by the use of HG-wort, Cooper, Stewart and Bryce [1] linked the higher level of yeast proteinase-A present in HG-wort to a loss in foam enhancing hydrophobic polypeptides in the fermentation process. While it had been previously suggested that hydrophobic foam enhancing substances were lost due to foaming in the fermenter, Cooper et al. [1] found this not to be true. This and related reports alerted brewers to the cause of poor foam stability and allowed them to take measures to increase the creation of foam active substances in the brewing process helping alleviate the action of proteinase-A.

Yeast Fermentation Performance - In high gravity brewing, the yeast is stressed more than usual, resulting in poor viability and performance when the yeast crop is reused or 're-cropped' during repeated fermentations. This problem was addressed by a number of publications by the Stewart research team. Notably, Cunningham and Stewart [2] reported that acid washing[§§] of the yeast from HG-wort resulted in poor fermentation performance and recommended the use of oxygenation to enhance yeast performance in HG-worts. This practice of HG-wort oxygenation enhanced both fermentation performance and extended the number of fermentations the yeast could be repitched, both major economic concerns of the industry.

Final Beer Flavour - When the first HG-worts were produced, brewers had great difficulty flavour-matching a brand of beer produced by normal strength (i.e., gravity) wort to the same beer brewed with HG-wort and then diluted. The first HG-worts were produced by adding high glucose syrups to normal gravity wort. In elegant work by Younis and Stewart [5] it was found that, while yeast-strain specific, the use of *maltose* based syrups, along with an increase of other wort nutrients improved flavour matching of normal to HG-wort beers. This breakthrough should not be understated. It is notable that following Professor Stewart's work, the majority of large brewers now use maltose-based syrups to produce their HG-worts.

§§ A technique used to rid the yeast of bacterial contaminants.

3. References to the research (indicative maximum of six references)

[1] Cooper, D.J., Stewart, G.G. and Bryce, J.H. 2000. Yeast proteolytic activity during high and low gravity wort fermentations and its effect on head retention. *J. Inst. Brew.* 106:197-201. http://dx.doi.org/10.1002/j.2050-0416.2000.tb00057.x

[2] Cunningham, S. and Stewart, G.G. 2000. Acid washing and serial re-pitching a brewing ale strain of *Saccharomyces cerevisiae* in high gravity wort and the role of wort oxygenation conditions. *J. Inst. Brew*. 106:389-402. http://dx.doi.org/10.1002/j.2050-0416.2000.tb00530.x

[3] Stewart, G.G. 2009. The Horace Brown Medal Lecture: Forty years of brewing research. J. *Inst. Brew*. 115:3-29. http://dx.doi.oeg/10.1002/j.2050-0416.2009.tb00340.x

[4] Stewart, G.G. and Murray, J.P. 2012. Brewing intensification – Successes and failures. *MBAA Tech. Quart*. 49:111-120.

[5] Younis, O.S. and Stewart, G.G. 1999. Effect of malt wort, very-high-gravity malt wort and very-high-gravity adjunct wort on volatile production in *Saccharomyces cerevisiae*. *J. Am. Soc. Brew. Chem*. 57:39-45. http://dx.doi.org/10.1094/ASBCJ-57-0039

These articles have been cited in a total of 85 publications as evidenced by Google Scholar. It is noteworthy that the application of these findings in industry is rarely reported and in fact, the implementation of industry practises changes following Professor Stewart's teachings are often considered confidential.

Grants

[G1] BBSRC 00/B1/D/06180 Role of lipid transfer proteins in foam stability during high gravity brewing £37, 715 10/1/2001 – 9/1/2004 (studentship)

[G2] BBSRC JE412544 (A) Studies on the malting and mashing properties of cereal grains for the production of beer and whisky £35,500 18/12/200 – 18/6/2001 (equipment)

4. Details of the impact (indicative maximum 750 words)

The impact of Professor Stewart's research, finding solutions for the problems preventing the commercial use of high-gravity brewing systems (please see section 2 above), and the resulting cost savings in the brewing and distilling industry are enormous. To quote a former Director of Brewing Operations of a US regional brewery and Past President of the Master Brewers of the Americas[S1],

> "The benefit of high-gravity brewing is something I've come to appreciate throughout my brewing career, and Professor Stewart clearly served as an authority and as an elucidator into underpinning effects of high-gravity brewing on yeast and in finished beer.
> What we all take for granted today is that high-gravity brewing has offered the most significant efficiency and productivity gain for any brewery in the world. It's been the most important means to increase plant capacity that brewing has ever experienced."

This same source [S1] has estimated the strength of US worts increased from 15^{o}P in 1993 to 20^{o}P in 2008 and 21^{o}P in 2013. In his regional brewery the starting wort strength of their flagship brand went from 10.8^{o}P in 1997 to 12.4^{o}P in 2008 to 13.2^{o}P in 2011[S1]. A second source has supplied worldwide estimates for starting wort strengths of 14^{o}P in 1993 increasing to 17^{o}P in 2008 reaching 18^{o}P in 2013 [S2].

This increase and the resulting economic impact made possible by the contribution of Professor Stewart's research are difficult to measure. However, one source [S3] has indicated that a 50% expansion of an 11.4 million hL/yr§§§ brewery built in 2007 in the US would cost approximately 50 million US Dollars. If one assumes this brewery made an increase of 5% in wort gravity (and assumes a linear interpolation of the above quoted expansion costs) the savings of using HG-wort to forgo capital expansion would be 5 million USD or 0.438 USD/hL. In the US, the volume of beer sold in 2011 was 225 million hL [S4]. If all US breweries increased the wort strength by 5% this would translate to capital savings of 98.6 x 10^6 USD or £65 million. It is notable that this cost estimate is based on US beer production alone. The world beer market was 1,925 million hL 2011! [S4]

Aside from direct savings in forgoing capital expansion by the use of HG-wort, additional and substantial savings result by the enhancement of sustainability in energy, effluent, cleaning costs, production flexibility and overall beer quality and stability. These savings are substantial but difficult to quantify. However, the savings in cleaning chemical costs alone by the use of HG-wort (therefore reducing vessels usage) has been estimated to range from 0.25 to 1.00 USD/hL produced [S5].

In addition, the world alcohol industry, totalling 825 million hL in 2012 [S6] has benefited from Prof. Stewart's research into minimizing yeast stress (Cunningham and Stewart, 2000) allowing increased efficiencies in the ethanol fermentation process when HG substrates are used. The resulting higher (fermenter) ethanol levels in turn, reduce the energy required for distillation. For example, the starting wort densities of a major Scottish grain whisky producer have increased 13% from 1993 to 2008 and 1.9% from 2008 to 2013. In the case of malt whisky, starting wort values have increased 3.5% from 1993 to 2008 and 1.7% in 2013 from 1993 values [S7].

The Scotch whisky industry alone produced 3.48 x 10^6 hL (on a pure ethanol basis) in the year ending October 2012 [S8]. These increases and subsequent capacity savings are not as dramatic as in the brewing sector but still contribute very substantially to companies bottom-line by reducing energy expenditures in the distillation process.

Therefore, by even the most conservative of estimates, the research undertaken a Heriot-Watt University from 1993 to 2008 has resulted in worldwide savings of £555 million§§§§ in capital cost savings of the brewing industries alone during 2008-2013.

§§§ hL = hectolitre (100 Litres).

§§§§ 1.925x10^9 hL* 0.438 USD/hL x 0.66 £/USD.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] Former Director of Brewing Operations of a US regional brewery and former President of the Master Brewers of the America, see comments in Section 4

[S2] Senior Director of Brewing in one of world's top five brewing companies by volume with 30-plus years brewing experience, "It is very hard to estimate the evolution of OG in the brewing industry, my personal estimates would have it move from 14p in 1993 to 17p in 2008 to now approaching 18p at industry level"

[S3] Sales and Commercial Director, Major International Brewery Equipment Supplier estimated a 50% expansion of an 11.4 million hL/yr§§§ brewery built in 2007 in the US would cost approximately 50 million US Dollars and was able to extrapolate savings of 5M USD.

[S4] E-Malt.com a subscription-based website, World Beer Production by Country 2000-2011. See statistics quoted above

[S5] Executive Technical Support Coordinator, Major International Provider of Cleaning Technologies and Services to the Food Industry will identify the savings in cleaning costs by using HG-wort.

[S6] Global Ethanol Production. http://www.afdc.energy.gov/data/tab/all/data_set/10331 , provides statistics to back up that the world alcohol industry, totalled 825 million hL in 2012 [S6]

[S7] Director, Major spirits manufacturer and senior council member of the Institute of Brewing and Distilling – see statistics in Section 4.

[S8] Sutherlands Edinburgh, Whisky Newsletter, Edinburgh, GBR. No 289:13. 2013 – see statistic in Section 4