Northern Periphery and Arctic Programme 2014-2020

EUROPEAN UNION
Investing in your future
European Regional Development Fund

# SYMBIOMA

Technology Innovations and Business Models for Valorisation of Industrial Waste Biomass in Sparsely Located Enterprises

# Side streams from brewery and distillery processes - quality and quantity


Author: Kilian Demmel*
Editors: Mikko Junttila, Egidija Rainosalo

# Contents



*This report is adapted from K.Demmel theses work for Centria University of Applied Sciences, September 2020 https://urn.fi/URN:NBN:fi:amk-202102132303

# 1. Side streams in beer and whisky manufacturing

## 1.1 Side streams in beer making

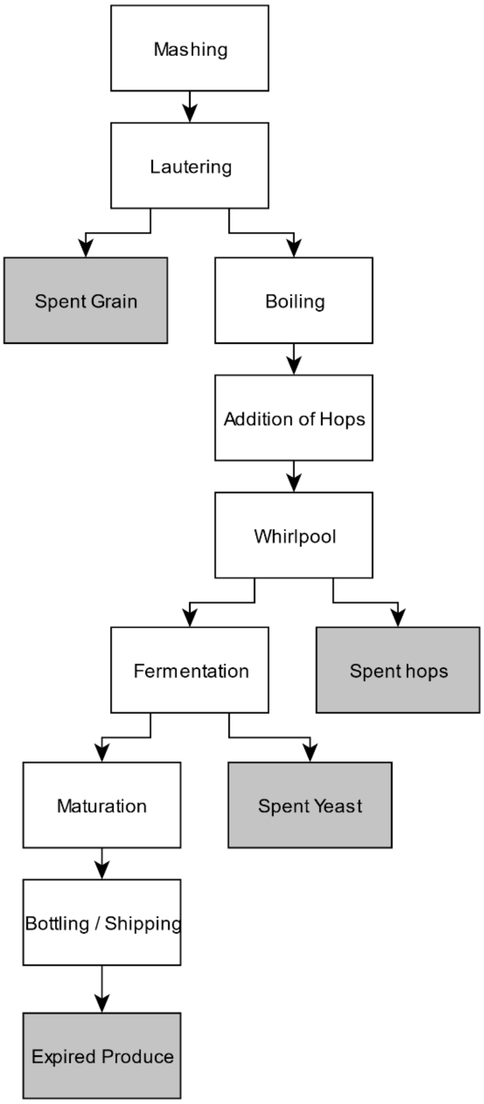


Figure 1. Process steps and major side streams in beer brewing.

Beer production is a multi-step process. During beer making different types of raw materials are needed in different process steps. Therefore, there are also several different types of side streams in beer making. The generation of these side-streams in their respective stages of brewing process as well as the medium amounts formed are detailed in Figure 1 and in Table 1. Clearly, mashing is the process step in which the most abundant solid side stream, spent grain is emerging. Milled malt, which is called grist, is transferred into the mash ton, where the mashing process takes place. Here the grist is soaked in 63-74°C warm water, causing the degradation of starch which in turn directly leads to maltose and dextrin. This is mostly done by α- and β-amylase (Back & Narziß, 2009, 238)[1].

The water which now contains the dissolved malt constituents is called wort. As the grains are not further necessary for beer production, they are removed in a process called lautering, which is mainly a physical separation process (Back & Narziß, 2009, 397). This process results in Brewers Spent Grain, which will henceforth be abbreviated as BSG. The amount of BSG can be as high as 20 kgs (wet form) per 1 hL of produced beer (dos Santos Mathias et al., 2014). When the wort has been separated from the solids, it is concentrated by boiling. Furthermore, boiling destroys the malt enzymes, stabilizes the wort, decreases the amount of coagulatable nitrogen, partially dissolves hop constituents and removes some of the more undesirable malt and hop aromas (Back & Narziß, 2009, 503).

Shortly before the end of boil, hops are added to isomerize their compounds and impart bitter flavor to the beer. Polyphenols contained within the hops assist the coagulation of proteins and hop essential oils are supposed to impart hop aroma in some beer styles (Back & Narziß, 2009, 544). The hops do not remain in the beer in most cases, but are removed before fermentation, resulting in spent hops (hot trub). The amount of spent hops varies from 0.2 to 0.4 kgs per 1 hL of produced beer (dos Santos Mathias et al., 2014)[2].

1 Back, W., Narziss, L. (2009). Die Bierbrauerei. Band 2: Die Technologie der Würzebereitung. 8th edition. WILEY-VCH.
2 dos Santos Mathias, T. R., de Mello, P. P. M., Sérvulo, E. F. C. (2014). Solid wastes in brewing process: A review, Journal of Brewing and Distilling, 5(1), 1-9.

Table 1. Side streams from the beer brewing process (adapted from dos Santos Mathias et al., 2014).

| Side stream | Amounts (kg/hL) |
|---|---|
| Spent grain (BSG) | 14 – 20 |
| Hot trub (spent hops) | 0.2 – 0.4 |
| Residual yeast | 1.5 – 3 |
| Diatomaceous earth | 0.1 – 0.2 |

The finished wort is chilled somewhere between 5-25°C while being transferred to a fermentation vessel and finally being inoculated with yeast. During fermentation, the yeast will convert sugars into mainly alcohol and carbon dioxide (Gastl et al., 2017, 231)[3]. Yeast also imparts flavor by producing higher alcohols, esters, carbonyls, and sulfur compounds. During the fermentation process yeast multiplies and forms significant amount of biomass. Yeast is removed to avoid autolysis and the negative effects thereof. Residual yeast from the fermentation is the second largest side stream in beer production and varies between 1.5 - 3 kg per hL of produced beer (dos Santos Mathias et al., 2014)[4]

After fermentation has taken place the leaving the brewer so called 'green beer', which must mature before it can be finally bottled and sold. Small amount of diatomaceous earth is also resulting from clarification and filtering process at the end of beer making. Filtration is needed to obtain stable and clear beer during the whole expiration period suggested (dos Santos Mathias et al., 2014). In some breweries, polyvinylpolypyrrolidone (PVPP) is used to prevent haze in the finished product (Barbose-Pereia et al, 2014).[5]

In Table 2 are presented the main components found in different brewery side streams. BSG, hot trub and residual brewery yeast have a rich composition of high nutritional value organic compounds such as fibers, proteins and vitamins. Phenolics can be found all side streams except residual yeast (dos Santos Mathias et al., 2014).

Table 2. Main components present in brewery side streams (dos Santos Mathias et al., 2014).

| Component | Brewer spent grain | Hot trub | Residual yeast | Diatomaceous earth slurry |
|---|---|---|---|---|
| Fibers | √ | - | - | - |
| Carbohydrates | - | √ | √ | - |
| Protein | √ | √ | √ | √ |
| Free amino acids | - | - | √ | - |
| Ash | √ | √ | √ | - |
| Vitamins | √ | - | √ | - |
| Phenolic compounds | √ | √ | - | √ |
| Fatty acids | - | √ | √ | - |
| Fossil materials | - | - | - | √ |

3 Gastl, M., Narziß, L., Back, W., Zarnkow, M. (2017). Abriss der Bierbrauerei. 8th edition. WILEY-VCH.
4 dos Santos Mathias, T. R., de Mello, P. P. M., Sérvulo, E. F. C. (2014). Solid wastes in brewing process: A review, Journal of Brewing and Distilling, 5(1), 1-9.
5 Barbosa-Pereira, L., Bilbao, A., Vilches, P., Angulo, I., LLuis, J., Fité, B., Paseiro-Losada, P., Cruz, J. M. (2014). Brewery waste as a potential source of phenolic compounds: Optimization of the extraction process and evaluation of antioxidant and antimicrobial activities. Food Chemistry, 145, 191-197.

### 2.1.1 Brewers' spent grain (BSG)

Composition of BSG is presented in Table 3. Water content in BSG is high 65 - 80 %. In dry BSG main constituents include fiber (30 – 50% w/w) and protein (14 – 30% w/w). Both are staple nutritional components in the human diet and thus make this material very attractive for improving the nutritional value of foods. In addition, several components that are constituents of BSG, such as hemicellulose (which is mainly arabinoxylans in BSG) (22 - 42% w/w), proteins (14 - 31% w/w) in the form of hydrolysates and phenolic compounds (0.7 - 2% w/w), have gained increasing attention for their health benefits. The rich fermentable polysaccharide and protein content and the high moisture content makes BSG susceptible to rapid microbial growth and subsequent spoilage. Currently BSG is used mainly as cattle feed. (Lynch et al. 2016)[6]

Table 3. Chemical composition of BSG (adapted from Lynch et al. 2016).

| **Component** | **g per 100 g dry material** | **Component** | **g per 100 g dry material** |
|---|---|---|---|
| Hemicellulose (arabinoxylan) | 21.8 – 41.9 | Lignin | 11.5 – 27.8 |
| Cellulose | 0.3 – 33 | Lipids | 3.0 – 10.6 |
| Starch | 1 – 12 | Ash | 1.1 – 4.6 |
| Protein | 14.2 – 31 | Phenolics | 0.7 – 2.0 |

### 2.1.2 Spent hops (hot trub)

Dry mass in spent hops (hot trub) is high, almost 90 % (w/w) as presented in Table 4. Major component in dry spent hops is fiber (~58 % (dw)), which includes cellulose, hemicellulose, pectin and lignin. Dry spent hops is also rich in proteins, 20 % (dw).

Table 4. Components and their amounts in spent hops (adapted from Ziemiński et al. 2012)[7]

| **Biomass component** | **Unit** | **Spent Hops** |
|---|---|---|
| Dry mass (DM) | [g/kg] | 890.00 |
| Ash | [g/kg] | 102.35 |
| COD | [g/kg] | 115.72 |
| Ammonium nitrogen | [g/kg] | 23.47 |
| Phosphorous | [g/kg] | 5.51 |
| Protein | [% DM] | 20 |
| Fiber, including: | [% DM] | 57.7 |
| Cellulose | | 19.6 |
| Hemicellulose | | 12.5 |
| Pectin | | 4.0 |
| Lignin | | 21.0 |

### 2.1.3 Brewers' spent yeast (BSY)

In fermentation yeast is added to brewing process to convert sugar in wort to alcohol and carbon dioxide. After fermentation, excess yeast is collected. Collected yeast can be re-used in the brewing process up to around six times. After which, it becomes brewer's spent yeast (BSY), the second biggest side stream from the brewing process (15% of total by-products generated). BSY is low in calories, fat and carbohydrates; however, it can be a valuable source β-glucans, vitamins and minerals. Several

6 Lynch, K. M., Steffen, E. J., Arendt, E. K. (2016). Brewers' spent grain: a review with an emphasis on food and health. Journal of Institute of Brewing. 122, 553-568.
7 Ziemiński, K., Romanowska, I., Kowalska, M. (2012). Enzymatic pretreatment of lignocellulosic wastes to improve biogas production. Waste management, Volume 32, Issue 6, Pages 1131-1137.

technologies have been developed to turn this waste into a valuable resource. As is BSG, BSY is also highly susceptible to rapid spoilage as a result of the activity of microorganisms. This has hindered large-scale reuse of BSY. Currently most of the BSY produced in Europe (some 125 000 tonnes/yr) is sold in its wet form as animal feed to farmers. Due to high drying costs only 10 % of the BSY is dried. (LIFEYEAST, 2021)[8]

Nutritional composition of brewer's spent yeast (BSY) extract is presented in Table 5. BSY extracts were produced by mechanic disruption of BSY (Saccharomyces pastorianus) and removal of the cell walls (fibers and β-glucans). Results showed that the extracts from the inner content of yeast cells are a rich source of proteins containing essential amino acids, RNA, vitamins (B3, B6 and B9) and minerals (Vieira et al, (2016)). [9]
Klis et al. (2002)[10] have reported that the yeast cell wall in brewer's yeast Saccharomyces cerevisiae is ca. 70 nm thick and accounts for ca. 20 % of the cell's weight. Three main groups of polysaccharides form the yeast cell wall: polymers of mannose covalently linked to peptides (mannoproteins, ca. 40 % of the cell wall dry mass), polymers of glucose (β-D-glucans, ca. 60 % of the cell wall dry mass) and polymers of N-acetylglucosamine (chitin, ca.2 % of the cell wall dry mass).

Table 5. Nutritional composition of brewer's spent yeast extract (adapted from Vieira et al. 2016).

| **Proximate composition** | **(g/100 g dw)** | **Trace elements** | **(mg/100 g dw)** |
|---|---|---|---|
| Moisture (%) | 7.70 ± 0.12 | Chromium (Cr) | 0.019 ± 0.000 |
| Ash | 14.0 ± 0.2 | Iron (Fe) | 1.76 ± 0.03 |
| Protein | 64.1 ± 0.2 | Manganese (Mn) | 0.564 ± 0.013 |
| α-amino nitrogen | 3.79 ± 0.23 | Cobalt (Co) | 0.030 ± 0.001 |
| Fat | 1.32 ± 0.04 | Molybdenum (Mo) | 0.003 ± 0.000 |
| Carbohydrates | 12.9 ± 0.1 | Zinc (Zn) | 11.9 ± 0.29 |
| RNA | 4.00 ± 0.16 | Copper (Cu) | 0.364 ± 0.001 |
| | Selenium (Se) | 0.030 ± 0.000 | |
| Macrominerals | (mg/100 g dw) | Vitamins | (mg/100 g dw) |
| Sodium (Na) | 1228 ± 22 | Nicotinic acid (B3) | 77.2 ± 1.1 |
| Potassium (K) | 9148 ± 69 | Pyridoxine (B6) | 55.1 ± 2.5 |
| Calcium (Ca) | 27.1± 0.40 | Folic acid (B9) | 3.01 ± 0.02 |
| Magnesium (Mg) | 273 ± 2.31 | | |

8 Lifeyeast (2021). https://lifeyeast.com/ [used 26 01 2021].
9 Vieira, E., Rocha, M. A. M., Coelho, E., Pinho, O., Saraiva, J. A., Ferreira I. M. P. L. V. O., Coimbra, M. A. (2014). Valuation of brewer's spent grain using a fully recyclable integrated process for extraction of proteins an arabinoxylans. Industrial Crops and Products. 52, 136-143.
10 Klis, F., Mol, P., Hellingwerf, K., & Brul, S. (2002). Dynamic of cell wall structure in Saccharomyces cerevisiae. FEMS Microbiology Reviews,26, 239–256

## 2.2 Side streams in whisky manufacturing

While the production of whisky is in parts like the brewing of beer, there are some key differences. Firstly, whisky is a distilled spirit while beer is not. Secondly, there are usually no hops added to the wort when whisky is made. The source material for whisky can be either pure malt or unmalted grains, depending on the type of whisky produced. Even though grain distilleries rely on unmalted grains as a base material for all further endeavors, they still require some of the enzymes that malted grain provides and therefore add a small fraction of it to their unmalted grain (Stewart et al., 2003, 75)[11].

The grain undergoes the mashing and lautering process, leaving the distiller with wort (Figure 2). Unlike brewers, distillers do not boil the wort (Stewart et al., 2003, 144). The fermented wort is then subjected to distillation, in which the more volatile compounds are separated from the less volatile ones, which remain as pot ale. During subsequent distillation, spent lees remain. During distillation, the head and the tails are separated as well, these are volatile compounds that are not desired in the finished product. The initial distillate may be distilled several times. (Stewart et al., 2003, 170). Afterwards the spirit is matured in wooden barrels, where it undergoes some chemical changes over time. The production of whisky mainly generates spent grain (BSG, also called draff), spent lees, spent yeast (BSY) and pot ale as side streams. BSG from production of whisky is similar type side product as is the BSG from brewing beer. A more detailed presentation of the production of whisky and the side streams from whisky manufacturing, see for instance Modinger, 2015[12].

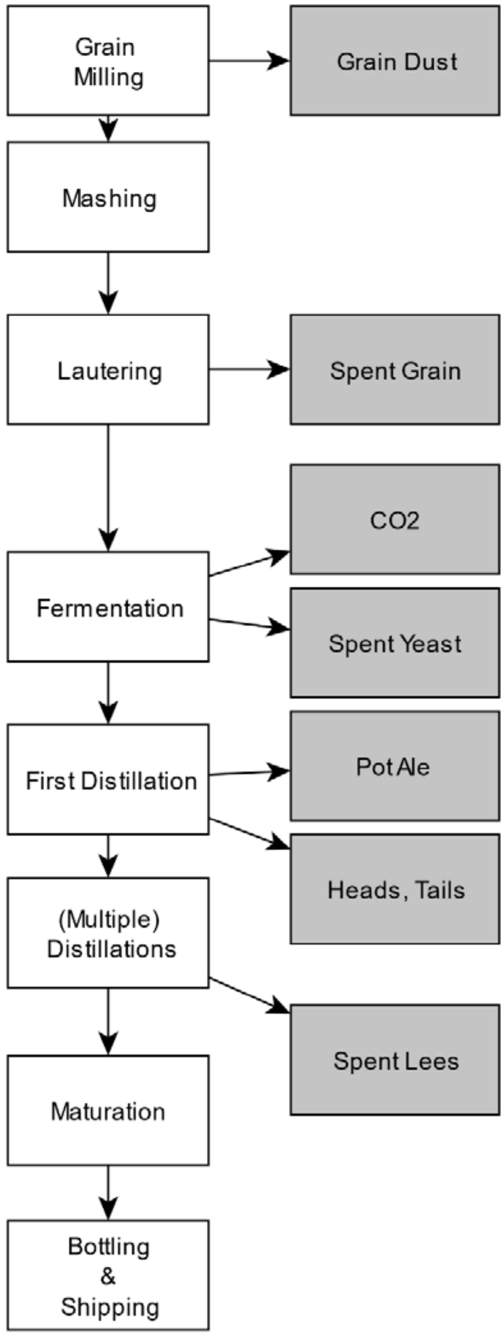


Figure 2. The whisky manufacturing process and the waste it generates.

### 2.2.1 Pot ale and spent lees

White et al, (2020)[13] have reported characteristics of pot ale from malt whisky distillery. Pot ale is as a brownish liquid with two distinct layers as presented in figure in Table 6. Insoluble solid, yeast fraction, settles to the bottom of container. The pH varies between 3.6 and 4.1, and is attributed to the concentration of volatile acids. The yeast content is approximately 2.9 × 108 cells/ml, and the total dry matter is 5.1%. The concentration of yeast cells is as expected with pitching at 3 – 4 × 107 cells/ml, typically leading to approximately 2 × 108 cells/ml in the washback at the end of the fermentation, and this yeast would be concentrated up to 2-fold in the wash still. The dry matter content is typically between 4 and 4.5%, although the yeast settles out quite quickly, so batch variation would be expected depending on sampling procedures. The insoluble dry matter is not solely due to yeast concentration

11 Stewart, G., Russell, I., Bamforth, C. (2003) Whisky. Technology, Production and Marketing. Academic Press.
12 Modinger, J. E. T. (2015). Thesis work: Protein recovery from whisky by-products: a study of using ion exchange chromatography for the recovery of proteins from pot ale. https://www.ros-test.hw.ac.uk/bitstream/handle/10399/3020/TraubModingerJE_1015_eps.pdf?sequence=1&isAllowed=y [used 26 01 2021].
13 White, J. S., Stewart, K. L., Maskell, D. L. Diallo, A., Traub-Modinger, J. E., Willoughby, N. A. (2020)- Characterization of pot ale from a Scottish malt whisky distillery and potential applications. ACS Omega. 5(12), 6429-6440.

with other insoluble components such as grain particles and bacterial cells mainly from lactobacilli being present, in addition to precipitated protein. Pot ale, apart from evaporation to pot ale syrup as a cattle feed, is primarily treated by anaerobic digestion or by land/sea disposal.

Table 6. Characterization of Pot Ale from a Malt Whisky Distillery (adapted from White et al., 2020).

| **Pot ale characteristics** [a] | |
|---|---|
| pH | 3.9 |
| Yeast (cells/ml) | 2.9x108 |
| Dry matter (% w/w) | 5.1 |
| Crude protein, CP (% DW) | 33.0 |

[a] The image on the right is pot ale in a collection container after the yeast and other insoluble solids have settled out.

In Table 7 is compered compositions of pot ale and spent lees. Spent lees is what remains after the first distillate is distilled again. Chemical oxygen demand (COD) tells what is the amount of organic matter in the sample. Biochemical oxygen demand (BOD) represents the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic (oxygen is present) conditions at a specified temperature. Both show that the amount of organic matter in pot ale is significantly higher than in spent lees. Also, all other parameters except level of copper are significantly higher in pot ale compared to spent lees. Only the level of copper in spent lees is higher than in pot ale. Copper vessels are used in distillations in whisky distilleries which can explain the difference in copper levels.

Table 7. Composition of pot ale and spent lees (Bennett et al. 2015)[14].

| **Parameter** | **Pot Ale** | **Spent Lees** |
|---|---|---|
| COD (mg/L) | 50,000-75,000 | 1,500-4,00 |
| BOD (mg/L) | 25,000-35,000 | 500-2000 |
| SO2-4 | 100-450 | <40 |
| PO3-4 | 150-600 | <0.5 |
| Cu (mg/L) | 2-12 | 8-50 |
| Cd (mg/L) | 0-0.035 | 0 |
| Al (mg/L) | 0.03-0.150 | 0.01-0.08 |
| Solid (%wt/wt) | 4-7 | 0.02-0.175 |
| Total Nitrogen (mg/L) | 2,000-4,000 | 100-150 |

14 Bennett, J. Walker, G. Murray, D. Akunna, J. Wardlaw, A. (2015). Avenues for bioenergy production using malt whisky distillery co products. Distilled Spirits, Future Challenges & New Solutions [Proceedings of the 5th Worldwide conference on Distilled Spirits, Edinburgh]. Context Publishers, Nottingham. Pages 303-312.

## Acknowledgements

This report is produced with part funding of the European Union (EU) Northern Periphery and Artic (NPA) Programme under the programme priority Axis 1- Innovation.
This is in the report for the WP 1 deliverable T 1.1.1 of the SYMBIOMA project (Technology Innovations and Business Models for Valorisation of Industrial Waste Biomass in Sparsely Located Enterprises. Case: Industrial Symbiosis for Valorisation of Waste Biomass from Food and Beverage Industries) (Project No. 352)

The project partners:

**Lead partner**

Centria University of Applied Sciences, Finland (CENTRIA)

**Other partners**

Institute of Technology Sligo, Ireland (ITSligo)

Norwegian Institute of Bioeconomy Research, Norway (NIBIO)

Bottenvikens Bryggeri Ab, Sweden (Bottenvikens)

Luleå University of Technology, Sweden (LUT)

Hermanni Winery Ltd, Finland (Hermanni)