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FIXING THE WATER-FOOD-ENERGY-NEXUS BY COMPLETE RECYCLING OF PROCESS WATER IN MALT INDUSTRY

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Summary:

Membrane bioreactor (MBR) technology is a promising method for water and wastewater treatment because of its ability to produce high-quality effluent that meets water quality regulations. In many industrial areas, organically polluted process water can be treated with MBR technology to such an extent that it can be reused in high quality. The ultrafiltration stage of the MBR process completely retains bacteria, so that a microbiologically excellent filtrate is generated. Figure 1 provides a very simplified overview of an MBR system.

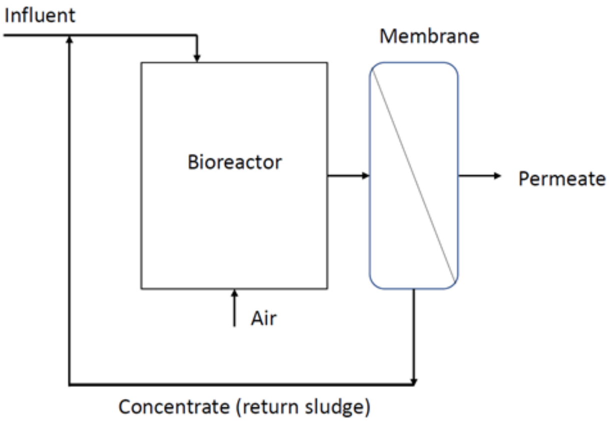

Figure 1: Simplified overview of an MBR system

In this report, the authors describe how an old SBR plant [Jäger, 2001] in a German malt factory was converted into an innovative MBR plant. Due to an expansion of production capacities in the malt factory, a concept which relieves the municipal sewage treatment plant was required. In preliminary studies it became already evident that the desired goals can only be achieved by implementing a process water recycling strategy into the plant concept.

In addition to saving fresh water and wastewater, a concept was developed to also use the MBR's excess biomass as valuable feedstock in a biogas plant and its digestate as organic fertilizer in the surrounding agricultural areas. The plant is therefore a great example of how a sustainable circular economy concept can be successfully included into an existing process.

Keywords: Membrane bioreactor, reuse, circular economy, industrial water

1) Introduction:

For industrial companies' water stress is one of the main drivers that induce them to deal with topics such as water reuse and water efficiency [Jäger, Lindemann, 2000; Jäger, 2001]. All four aspects: technology, the use of process water, better monitoring and leak detection, do work together hand in hand. As a beneficial result, companies can better assess and optimize their water footprint by updating partial processes, consumers and auxiliaries. Table 1 gives an overview of membrane processes and their areas of application [12].

Table 1: Membrane processes and their areas of application

Removable water ingredients	Separation limit (Pore size)	Process (membrane type)	Operation pressure kPa (bar)
Particle > 0,1 µm emulsified substances	0,1 – 1 µm	Microfiltration (MF) (Pore membranes)	50 – 300 kPa (0,5 – 3 bar)
Colloids, Macromolecules molar mass > 2.000 g/mol emulsified substances	2.000 – 200.000 g/mol (0,004 – 0,1 µm)	Ultrafiltration (UF) (pore membranes)	50 – 1.000 kPa (0,5 – 10 bar)
Organic molecules Polyvalent, inorganic ions	200 g/mol retention for $MgSO_4$ > 90% (0,001 – 0,005 µm)	Nanofiltration (NF) (Solution diffusion membranes with built-in ionogenic groups)	500 – 4.000 kPa (5 – 40 bar)
Organic molecules and all ions	< 200 g/mol retention for NaCl > 95%	Reverse osmosis (RO) High pressure – RO (HD-RO) (Solution diffusion membranes)	500 – 7.000 kPa (5-70 bar) To 12.000 kPa (to 120 bar)

2.1 Malting

Malting is used to produce malt from brewing grain. There are around 180 countries over the world with breweries, but only around 50 countries with operated malting plants.

Historically breweries produced their malt themselves and were therefore a brewery and malt house in one. Particularly from the second half of the 19th century distinctive brewery and malting plants emerged. [1] Nowadays, only very few breweries continued producing their malt themselves. With increasing industrialization in the middle of the 19th century, the production of malt separated from the production of beer and malting plants became more and more independent companies. Nevertheless, malting is inextricably linked to brewing. The profession of brewer and maltster combines both fields of activity [Rieseler, 2003].

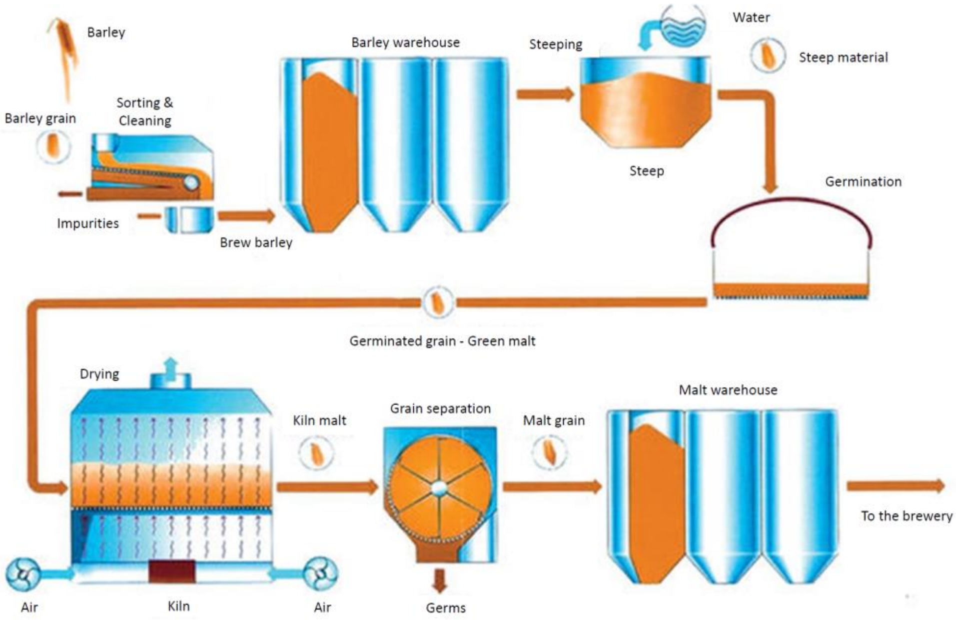

Figure 2: Process steps of malt production

Malting is the controlled germination of cereals to turn barley into a friable, easily milled malt. The barley grain will only grow when immersed in water, which is done through the so called steeping process. During the steeping the water content of the grains raises from 14% to 45%. Afterwards the germination is stopped by drying the barley in a hot air kiln. This process creates a malt, which is rich in flavors, natural enzymes, starch, protein and minerals. [Schuster, Weinfurtner, Narziß; 2018].

The production of malt can be divided into three process steps:

I. Steeping:

During the steeping the barley (or other brewing grain) is moistened for two to three days, until the water content of the grain is around 40 to 45%.

II. Germination:

The steeped barley germinates in special germinators for four up to seven days. Leaf and root germs form from the seedling of the grain and enzymes are formed or activated in the grain during this process step.

III. Kilning:

The germinated malt is gently dried in the kiln. Due to this color and aroma substances are formed in the grain. Different malting processes can be used to produce many different brewing malts, which enable brewers to create different types of beer.

2.2 Membrane Bioreactor (MBR) Technology

The MBR process is a combination of biological wastewater treatment comprising the activated sludge process and a phase separation stage separating the sludge-water mixture by membrane ultra-filtration.

The wastewater is cleaned from organic pollutants by microbes, using these pollutants as feedstock for their metabolism in the biological stage of the treatment system (activated sludge process). In simple terms, the carbon and nitrogen compounds in the wastewater are converted into CO_2, N_2 and incorporated into microbial biomass. These microorganisms are suspended in an aerated tank as sludge flakes.

The MBR process is a combination of biological wastewater treatment using the activated sludge process and a phase separation of the sludge-water mixture using membrane filtration.

To separate the biologically treated wastewater from the suspended biomass, special pressurized micro- or ultrafiltration membranes are used. These membranes ensure complete biomass retention, so that a secondary clarifier is not required. The result is a solids-free, largely cleanliness and purified filtrate (i.e. permeate).

The biodegradability of soft barley water in general is good. The ratio of COD to BOD is in the range of 2. The degradability is therefore generally assessed as good and the presence of toxic substances is negated. With steep water, not all the organic load is broken down. It can be expected that a residual portion of the COD can only be biodegraded very slowly or not at all. This is also reflected in the wastewater ordinance, which is based on the state of the art and requires a limit value of 110 mg O_2/l for clarified malting water.

Figure 3 provides an overview of a conventional sewage treatment plant and a membrane bioreactor plant.

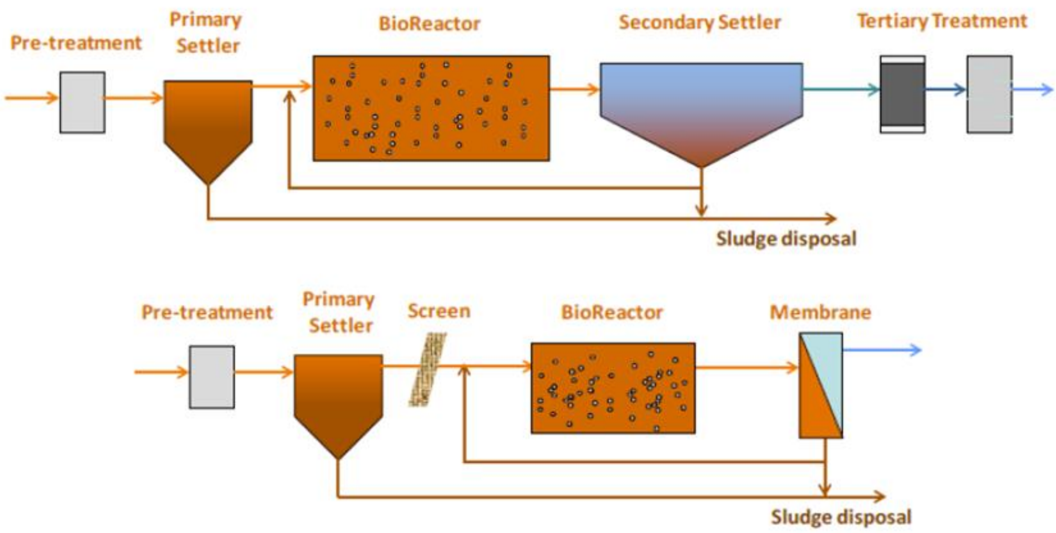

Figure 3: Comparative illustration of conventional wastewater treatment plant versus MBR

2) Tasks

Especially in connection with the reuse of steeping water in a malthouse the question of steeping water quality is of major importance.

- steeping water quality must ensure a rapid and even water uptake as well as a enough washing of the grain.
- elimination of easy biodegradable substances (reduction of COD and BOD)
- salt concentration in steeping water at the beginning of the steeping process should not exceed 2,500 µS/cm (conductivity) – otherwise negative effects on germination of sensitive barley lots possible.

Steeping water should be free from microorganisms (especially bacteria and moulds) out of legal and technological reasons.

3) Plant Design

The original wastewater treatment plant of the malt factory consisted of a biological treatment via Sequencing Batch Reactor (SBR) technology and subsequent discharge of the treated water into the local sewer. Due to its age the plant was in no good condition and could not be used to establish a water recycling concept out of both, technological and legal reasons. For the MBR concept, equipment of the old plant, such as tanks, were re-integrated into the new treatment system.

Figure 4 provides a general overview of the new plant concept.

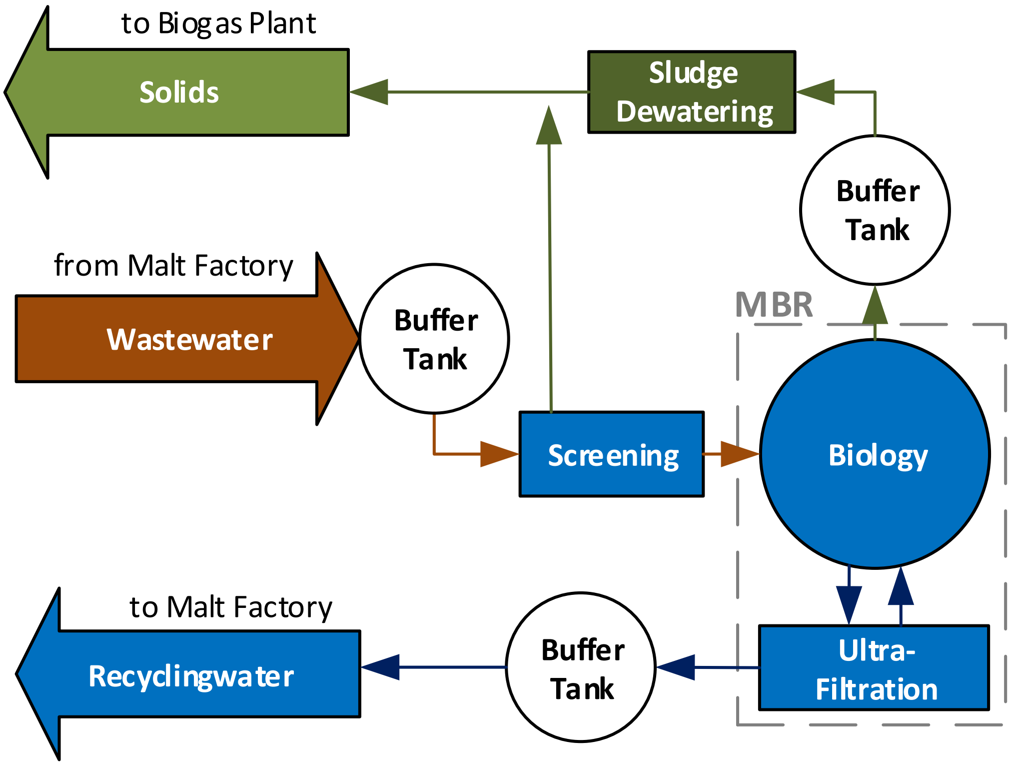

Figure 4: Illustration of the general plant concept

Firstly, wastewater production and its treatment were hydraulically unlinked by integrating a buffer tank. As malt factories tend to produce large hydraulics of wastewater (in our project approx. 200m³ of wastewater within 15 to 20 minutes), it is beneficial to buffer the water and bleed it into the plant's subsequent biological treatment stage to reduce stress to the bacteria due to feedstock overloading. From the upfront buffer tank the biological stage of the MBR process is homogeneously fed with wastewater. Within the feeding line of the MBR a screening system is installed to remove coarse particles, such as remaining grains and leaves, from the stream.

The MBR system comprises an aerated tank (i.e. *Biology*) plus biomass-retention system via ultrafiltration. Inside the *Biology* tank, fresh wastewater is mixed with wastewater which is already inside the tank. Inside the tank microorganisms are dispersed as sludge flakes. The sludge-wastewater-mixture is aerated via a submersed aggregate, providing ambient oxygen to the microbes while mixing the system at the same time. The demand of aeration is monitored and controlled via an oxygen probe in the system.

The *Biology's* containment is pumped into the ultrafiltration (UF) stage continuously and partially re-cycled into the *Biology* tank via the *UF feed loop*, which also contains various analytical equipment, such as probes for pH/temperature, oxygen concentration and electrical conductivity.

From the *UF feed loop* the wastewater-sludge-mixture is fed into the UF membranes; for this project's treatment system an external UF module configuration type, operated in crossflow mode was chosen. In this system the wastewater-sludge-mixture from the *UF feed loop* is passing through tubular membrane modules, in which water permeates through the semi-permeable membranes and leaves the treatment unit as cleaned *permeate*, good for recycling. To the *permeate* Sodium Hypochlorite as disinfectant is added flow-proportionally while pumping the *permeate* into the recycling water buffer tank, supplying the malt factory's production units with water. Inside the buffer tank the recycling water quality is monitored (e.g. pH/temperature, electrical conductivity) and additional drinking water from the grit can be added, in case of water shortage.

The wastewater-sludge-mixture which completely passes the tubular membrane modules contains the valuable microorganisms as sludge, which are required for the biological treatment and is therefore recycled back into the Biology as *retentate*.

As some of the organic pollutants inherent in the wastewater are consumed by the microorganism's metabolism and converted in to biological grows (i.e. biomass growth due to reproduction), the amount of sludge in the Biology tank will increase over time. Without any external control, this will cause problems to the system, such as reduced efficiency due to inhibition, clogging of the UF system, etc.

Hence, the system is equipped with a biomass extraction system: on a regular base some Biology contents are transferred into a third buffer tank, the *sludge buffer tank*. From this tank a dewatering screw press is fed, separating the wastewater-sludge-mixture into a solids-reduced liquid and a solids-rich sludge (see figure 5).

Figure 5: photograph of dewatered excess sludge for use as biogas plant feedstock

Before dewatering the wastewater-sludge mixture polyelectrolyte solution (i.e. polymer) is added to enhance growth of larger particles and to support dewatering efficiency of the system. Afterwards, the mixture is separated into a liquid and solid phase. Since polymer was added to the water, recycling of the liquid phase back into the treatment system and therefore back into the malt factory is prohibited. Therefore, this comparably small amount of liquid is released into the local sewer for further treatment. The solids are collected in a skip and are transferred and fed into a neighboring biogas plant as valuable substrate.

For most of the new plant's equipment installation into 40-foot containers was favored.

This concept allows for

- pre-fabrication and testing of the systems in the suppliers' workshops
- small on-site footprint
- parallel work on containers and on-site installation and pipework
- short time for integration into the existing plant
- extendibility due to modular plant design

Figure 6 a-c: Further impressions of the installations

4) Operating Results

The operating results and literature [Schildbach, 2002] knowledge can be generalized as follows regarding the nature of recycling water for soft purposes:

- Sterility (disinfection via a physical germ barrier [here: membrane)):

  Fulfillment of the minimum requirement in accordance with the Drinking Water Ordinance (orientation on the epidemiological parameters)

  For technological reasons due to the risk of bacterial inhibitor formation (organic acids, NO_2 ...)

Table 2 gives an overview of the microbiological results when using sodium hypochlorite at different concentrations

Table 2: Microbiological results with different concentrations of Na-Hypochlorite

Sample No.	CB_1001	CB_1002	CB_1003
Date	23.07.2019	29.07.2019	29.07.2019
Sample volume	250 ml	250 ml	250 ml
Sample vessel	PE-sterile	PE-sterile	PE-sterile
Temperature	33°C	33°C	31°C
Na-Hypochlorite	0 mg/l	0,05 mg/l	0,1 mg(l
Coliforms CFU/100 ml	0	0	0
Escherichia coli	0	0	0
CFU 20°C	1	0	0
CFU 36°C	18	1	0
Pseudomonas aeruginosa	0	0	0

The combination of ultrafiltration and subsequent hypochlorite dosing provides a stable, reliable, sterile environment for the permeate.

- Removing biodegradable substances

  Due to the risk of recontamination with the corresponding consequences

- Salt concentration maximum 2,500 µS/cm:

  For technological reasons due to the risk of impairing germination/malt solution in sensitive areas of barley.

With this system, very stable salt contents with an electrical conductivity of around 2,100 µS / cm can be maintained. This is essentially due to the fact that the process water which evaporates in the kilns is replaced by soft city water (approx. 900µS / cm).

The two-stage recycling process used to replenish water losses through freshwater (municipal or well water) can therefore be used from a hygienic and technological point of view. Compared to the freshwater steep, it leads to equivalent malts and beers and can be recommended from the technical implementation and the calculated and actual costs.

5) Outlook

These methods for saving fresh and wastewater are increasingly in demand to industries. By combining different treatment steps (chemically, biologically, physically) it is now possible to generate process water of the highest chemical and microbiological quality. Membrane processes provide microbiological barriers that guarantee desired water quality cost-effectively.

By combining MBR and downstream reverse osmosis, both organic soils and salts can be eliminated almost completely. The implemented technology is transferable to many other industries and applications.

Since it is a containerized system, it is particularly suitable for retrofitting existing plants.

The modular design also enables a high degree of standardization and systems can be easily expanded. To save space, the containers can also be positioned one above the other, allowing even existing plants with only small available footprint to enjoy the benefits from this technological concept.

6) Benefits for the client

By installing the process water treatment plant, our customer is now able to reduce its water and CO_2 footprint drastically.

After installing the plant, it be possible to save 110,000 m³ of fresh and wastewater per year, which is equivalent to the demand of a small village.

In addition, these measures save more than 170,000 kg of CO_2 equivalent per year. Excess biomass is extracted from the biological treatment stage and used as valuable substrate in a nearby biogas plant. The biogas produced here is converted into electrical energy and heat in an efficient CHP plant.

The resulting digestate is then applied as fertilizer on regional barley cultivation areas, closing nutrient cycles sustainably.

The concept is coherent and offers an almost complete recycling, and is as such exemplary in the circular economy

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