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Minimisation of freshwater consumption in brewery

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The current drive towards environmental sustainability and the rising costs of freshwater and effluent treatment have induced the process industry to find new ways in freshwater consumption and waste generation reduction. Excluding process changes, there are three approaches to reduce the freshwater demand: re-use regeneration-reuse and regeneration recycling. The paper presents the opportunities of water re-use in batch processes using a brewery as an example.

In the first stage, water balance was obtained and the most critical processes were identified comparing their water consumption with values given in Reference Document on Best Available Techniques in the Food, Drink and Milk Industries (2006). In order to estimate possibilities of water re-use the maximal inlet values of contaminants (COD, pH and conductivity) were determined for each water consumer and its flow rate was measured. The process has been simulated, and software for Pinch Analysis of continuous processes was applied. Because of the time dependence of water demand and waste sources available in batch process the feasibility of the proposed solution was reconsidered based on plant data. The time gap between source and demand could be solved by installing storage tanks. The water consumption could be reduced by re-using the outlet stream of bottle washer (returnable glass bottles) in the crate washer, and by collecting and redistributing water for beer charger rinsing at smaller consumers like bottle labeller or bottle inspection system. Outlet water streams of the rinser for cans could be reused as inlet stream to tunnel pasteurizer.

1. Introduction

The complexity of batch process industries lies in the fact that the production processes consists of elementary tasks with operating conditions and resource demand varying with time. Two main approaches are generally used to address the issue of minimisation of freshwater demand, i.e. the graphical approach and mathematically-based optimization approach.

Wang and Smith (1995) initiated a graphical design method based on water Pinch Analysis, where they combined the time constraint with concentration driving force constraint. In the first stage, a limiting water profile was introduced to locate the minimum fresh water and wastewater flow rates prior to detailed network design. The opportunities for regeneration–reuse and regeneration–recycling were also explored. The targeting was carried out on a flow rate vs. time diagram, where it was difficult to conceptualize the system interaction between concentration, flow rate and time simultaneously. The targeting and design became complex and time-consuming and, therefore, difficult to apply to large and complex situation. Foo et al. (2005) developed a two stage procedure to synthesize the maximum water recovery network for a batch process system. The first stage of the synthesis task was to locate the overall and the interval-based minimum freshwater and wastewater flow as well as storage capacity target using the time-dependent water cascade analysis technique. In the second stage the maximum water recovery network was developed using the time-water network in order to achieve the established water target. Majozi et al. (2006) presented a graphical method where, in the first instance, the time dimension was taken as a primary constraint and concentration a secondary one. Subsequently, the priority of constraints was reversed to demonstrate the effect of the targeting procedure on the final design. The graphical techniques are limited on processes characterized by a single contaminant, and they are based on the assumption that a fixed optimal production schedule exists. In addition, they can only handle quantitative rather than economic objectives.

Almato et al. (1999) developed an optimization framework for water use in batch processes. A superstructure model between tank and water consuming units was built to determine connections and flow rates between tanks and units automatically. The NLP (non-linear programming) model was optimized by simulated annealing and deterministic method. Disadvantage of the model was that water streams generated at different times were mixed in the same storage until the water was re-supplied to other water using operation. This inappropriate mixing reduced driving force and water re-use possibilities. Therefore, large and unnecessary storage tanks might be required. To overcome this drawback Kim and Smith (2004) developed a design method where the water recovery was limited through time constraint. The model allowed economic calculation to consider freshwater cost, storage tank costs, and piping costs. The resulting optimisation problem is a mixed integer non-linear programme (MINLP). The authors suggested an iterative scheme between MILP and LP to deal with the MINLP. Majozi (2005) presented a continuous-time mathematical formulation for freshwater minimisation with and without central reusable water storage. The model is based on superstructure presentation.

The fresh water consumption of modern breweries generally ranges from 3.7 L/L to 4.7 L/L of beer sold. The volume ratio of water to finished beer is depending on the technical standard of individual production units forming the overall brewery process. Table 1 shows a distribution of water consumption within a typical brewery according to the BREF (2006) and to the publication of European Brewery Convention, EBC (1990). The volume ratio of water consumption can bee expressed per volume of beer produced or per volume of beer sold. We need to point out the correlation between water consumption of washing process and the production structure. A bottle washer consumes more water than a can washer, which just rinses out the cans. Also, the water requirement is lower in case of non returnable glass bottles washing, than in returnable ones.

Table 1. Water consumption for different brewery processes

Department	BREF Ψ (water / beer produced) (L/L)	EBC Ψ (water / beer sold) (L/L)	
		Good practice	Best practice
Brewhouse to wort cooling & CIP	1.3–2.36	1.75	1.48
Fermentation and yeast handling & CIP	0.32–0.53	0.09	0.05
Maturation & CIP	0.24–0.67	0.09	0.05
Filtration & BBT & CIP	0.31–1.09	0.28	0.06
Keg washing (50 % of production)	0.59–1.63	0.34	0.17
Bottle washing (25 % of production)	0.13-0.61	0.23	0.13
Bottle and can pasteurisation	–	0.16	0.08
CIP (bottling cellar)	–	0.42	0.20
Water treatment conversion	–	0.2	0.16
Boilers	–	0.36	0.16
Evaporative cooling towers	–	0.55	0.38
Air compressors & CO_2	–	0.06	0.04
Total	3.7–4.7	4.53	2.96

2. Industrial application

In case of the brewery studied the volume ratio of water consumption to beer sold was 6.04 L/L or 653 300 m^3/a. Compared with the ratio specified by BREF, the fresh water consumption exceeded the upper limit by 144 900 m^3.

In the first stage water balance was obtained and the most critical processes were identified comparing their water consumption with values given in BREF and by EBC (Table 1).

Results of the flow rate measurements indicate that the brewhouse has good practice. Additionally, the water consumption ratio of individual process stages was tested. Table 2 gives a review of water consumption inside the brewhouse reported by the German brewing industry.

Table 2. Water consumption for different brewery processes

Process step	Ψ (water / beer sold) (L/L)
Gyle (unfermented wort) to whirlpool	1.8–2.2
Wort cooling	0.0–2.4

The brewery studied had multifunctional fermenters which made impossible the separation of water consumption in fermentation and maturation process. The value of water consumption ratio was inside the range defined by BREF, but considerably over the good practice requirement. Filtering results have shown a similar situation. Based on this result the cellar with filters was marked as one of the critical points in the brewery.

The specific water consumption of packing area was also higher than the specified BAT value. Aiming to reach the upper limit, the water consumption needed to be reduced by 68 000 m^3, approximately. The water consumption ratio of individual washers was also revised. The data of water consumption for different washers is shown in Table 3.

Table 3. Water consumption for different packaging material

Packaging material	Ψ (water / beer sold) (L/L)
Returnable glass bottles	1.3–3.5
Non returnable glass bottles	0.7–1.4
Cans	0.4
Kegs	0.3–1.3

Higher water consumption was observed in case of bottle washing (returnable glass bottles), CIP system, and pasteurisation. The energy system of the brewery studied had the best practice from the aspect of water consumption.

The fluctuation of contaminants (COD, pH and conductivity) was monitored in inlet and outlet water streams simultaneously with the water balance determination. The measurements were carried out for three months, during the highest production rate. The results of laboratory measurements have shown a strong influence of production intensity and packaging material type (returnable or non returnable glass bottles) on outlet water quality. The average COD value from the washer for non returnable glass bottles was 34 mg/L. In case of returnable glass bottles the COD value was in rage from 200 to 460 mg/L. Variability in the dirtiness of the returnable packaging material and craters can result in extremely high COD values. For example, the average COD value from cater washer was 50 mg/L, but in case of rather dirty caters the COD value can reach 1 600 mg/L. Based on these measurements the maximal inlet values of contaminants were determined for each water consumer.

2.1 Results

The process has been simulated using software for Water Pinch Analysis as a continuous one. Because of the time dependence of water demand and waste sources available in batch process, the feasibility of proposed solutions was reconsidered based on plant data. The water re-use opportunities were a priori investigated for the packing area, the most critical department in the brewery.

In case of the packing line for returnable glass bottles, water consumption could be reduced by reusing the outlet stream of bottle washer in the crate washer. Discharge of wastewater from bottle washer occurs daily, while from the crate washer it does weekly. That means that the crate washer needs to be filled up with the last discharge from bottle washer at the end of the week. The crate washer spray nozzles will have to be modified in order to avoid the clogging problem that occurs when using the bottle washer effluent. It may be necessary to install a screening device to eliminate suspended solids from the bottle washer discharge. The use of a screening device will also reduce the suspended solids loading, discharged from the bottle washer to the sewer. The volume flow rate of the potentially saved water was estimated to 3 400 m^3/a. The investment was estimated to be 590 EUR and the potential payback period was 1.1 months. Smaller consumers like bottle labeller or bottle inspection system can be eliminate fresh water consumption by collecting and redistributing water for beer charger rinsing. In this case a storage tank needs to be installed. The chargers were rinsed daily twice according to the production requirement and automatically in case of malfunction of the packaging line. The investment was estimated to be 40 500 EUR. The volume of the water saved by using this solution is small, resulting in a long payback period (4 year). Additional disadvantage is its strong dependence on the packing line efficiency.

The outlet water stream of the rinser for cans could be reused as inlet stream to tunnel pasteurizer. The volume flow rate of the water saved was estimate to 14 800 m^3/a. The investment was estimated to be 590 EUR and the potential payback period was eight days. The connection between equipment is direct, without need for storage tank installation.

Based on the COD, the outlet stream of the rinser for non returnable glass bottles also appears to be a potential inlet stream to tunnel pasteurizer, but because of the quality regulation for pasteurisation it cannot be used.

The outlet streams in the brewhouse and cellar have too high COD or conductivity for re-use without regeneration. With the suggested re-use items the brewery could save about 7 % of the current freshwater demand.

3. Conclusions

Using the principles of Water Pinch Analysis several water re-use opportunities were identified in the brewery. The solution offers water saving on packaging line for returnable glass bottles and for cans, both with acceptable payback period. The effect of water re-use on water consumption ratio is shown in Table 4. The values in fourth column (BREF) represent the overall volume ratio of water consumption in specified departments (e.g. value for packaging area is a sum of volume ration for keg and bottle washing, bottle and can pasteurisation and CIP system).

Table 4. The water consumption ratio without and with re-use

Department	Case studied brewery No re-use Ψ (water / beer sold) (L/L)	Case studied brewery With reuse Ψ (water / beer sold) (L/L)	BREF Ψ (water / beer produced) (L/L)
Brewhouse to wort cooling & CIP	**1.63**	**1.63**	**1.3–2.36**
Fermentation, maturation and yeast handling & CIP	**0.79**	**0.79**	**0.87–2.29**
Energy system	**0.388**	**0.388**	–
Packaging	**1.92**	**1.78**	**0.72–2.24**
Total	**4.73**	**4.59**	**3.7–4.7**

The water consumption in packaging area can be reduced by 45 410 m^3/a, the new value of water consumption to beer produced ratio would be 2.43 L/L (2.84 L/L without re-use). The overall water consumption to beer sold ratio would be reduced to 5.32 L/L. The new value is still higher then the upper limit defined in BREF (4.7 L/L). Further reduction in water consumption requires a modern technology implementation and consideration of water saving by regeneration-reuse, especially in the brewhouse and cellar. In the brewhouse, the condensate from wort boiling and the CIP rinsing water was considered for reuse. The condensate, has high COD value, the volume of the condensate was evaluated to be 33 300 L/a. The COD can be reduced with electrolytic treatment based on hypochlorous acid generation, Vijayaraghavan et al. (2006), or with membrane process (e.g. nanofiltration). Inversely the CIP rinsing water has low COD, but high conductivity value (3 046 µS). In the cellar the rinsing water of the filters has acceptable COD value, and can be used for floor wash, without regeneration, but the estimated volume of this water is just 170 L/a. In order to satisfy the environmental protection requirements, the temperature of wastewater from energy system needs to be cooled before releasing into river. In order to reach the specified temperature, the wastewater is mixed with fresh water (approximately 2 000 L/a). This volume can be saved by mixing with cold wastewater or with prolongation. These results will be used as a starting point for further investigation of water demand reduction using mixed integer linear programming (MINLP).

4. References

Almato M., A. Espuna and L. Puigjaner, 1999, Comp.Chem. Eng., 23, 1427–1437.

BREF, Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2006. European Commission, Seville.

EBC, Manual of Good Practice: Water in Brewing, 1990. European Brewery Convention, Nürnberg.

Foo C. Y., Z. A. Manan and Y. L. Tan, 2005, Journal of cleaner production, 13, 1381–1394.

Kim J. K., R. Smith, 2004, Trans IChemE (B3), 82, 238–248.

Majozi T., 2005, Comp.Chem. Eng, 29, 1631–1646.

Majozi T., 2006, Journal of Environmental Management, 78, 317–329.

Vijayaraghavan K., D. Ahmad and R. Lesa, 2006, Ind. Eng. Chem. Res., 45, 6854–6859.

Wang Y. P. and R. Smith, 1995, Trans IChemE (A73), 905–91.