Conversion of organic compounds into biogas on a full scale brewery WWTP using IC reactor

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Abstract. Wastewater from breweries usually contains high levels of organic components, which are generally easily biodegradable. Ideally, the mainstream method of brewery wastewater treatment is based on biological transformation, which have been reported to be effective in efficiently reducing COD concentration. Anaerobic digestion technology plays an important role in the treatment of high strength wastewater [1]. The benefit of the process is biogas production and recovering the energy. The main goal of the paper is to present the results of a full-scale research performed in a brewery WWTP in 2016. Wastewater from brewery containing COD, a priority pollutant of organic components, is treated in IC reactor. The biogas produced during the anaerobic digestion is transformed into heat. Total COD and soluble COD were measured 5 days a week in wastewater before and after anaerobic reactor. In raw wastewater, average total COD was 5226 mg/L with the percentage share of soluble COD 89.4%. As a result of anaerobic treatment 83.7% reduction of total COD and 92.9% reduction of soluble COD were obtained. The average daily biogas production was 4089 m³/d.

1 Introduction

The amount of water needed to brew beer is several times the volume actually brewed. Large volumes of water are being used by the industry to produce beer for two distinct purposes: as the main ingredient of the beer itself and as part of the brewing process for steam raising, cooling, and washing of floors, packaging, cleaning of the brew house during and after the end of each batch operation [2]. The beer brewing process generates large amounts of wastewater. Brewery wastewater typically has a high chemical oxygen demand (COD) from all the organic components (sugars, soluble starch, ethanol, volatile fatty acids, etc.) [4, 5]. Janhom et al. [3] have reported that the majority of organic compounds are in dissolved form. Wastewater usually has temperatures ranging from 25°C to 38°C, but occasionally reaching much higher temperatures. The pH levels can range from 2 to 12 and are influenced by the amount and type of chemicals used in cleaning and sanitizing [4, 5]. The brewery wastewater is characterized by large variations in the parameters and require some degree of

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pretreatment. If the brewery wastewater is discharged into the waterway, primary and secondary treatment is required. However, if the brewery is permitted to discharge into a municipal sewer, pretreatment may be required to meet municipal bylaws or to lessen the load on the municipal treatment plant [5]. Due to the organic compounds and high temperature, anaerobic purification is justified. Anaerobic treatment of brewery wastewater allows for removal of about 90% of the BOD. Furthermore, anaerobic treatment generates biogas – a renewable energy. In this paper, the results of an application of a full scale IC reactor in Poland will be presented, with particular attention drawn to the conversion of organic compounds into biogas.

2 Materials and methods

The research was conducted at the brewing pretreatment plant in 2016. WWTP was designed for a flow of 5500 m³/d and COD of 4000 mg/L.

The first part of the treatment system is the screen. Next, sewage flows into equalisation tank. Biological treatment takes place in the IC reactor of 24 m height and a capacity of 1192 m³. The temperature of the wastewater in the reactor should be 35°C.

The maximum OLR assumed for this project is 18.5 kg COD/m³·d. Biogas formed in the fermentation process is cleaned.

Treated wastewater is discharged into the sewer. TCOD value at the effluent should be lower than 1400 mg/L.

Samples of influent and effluent from the reactor were taken 5 days a week. The scope of the research included the measurement of the following parameters:

TCOD – Hach cuvette test LCI 400, LCK514, LCK 914,

SCOD – centrifuge of the sample (3500 rpm, t = 10 min), Hach cuvette test LCI 400, LCK514, LCK 914,

TSS – PN-EN 872:2007

The pH was measured on-line. The daily volume of biogas was measured and calculated to the volume of the biogas produced from influent COD ($V_{\text{COD in}}$) and removed COD ($V_{\text{COD rem}}$). Moreover, ORL and HRT were calculated. Influent into IC reactor were characterized by pollution indicators presented in the Table 1.

Table 1. Characteristic of influents into IC reactor.

Parameter	pH	Flow, m ³ /d	TCOD, mg/L	SCOD, mg/L	SCOD/TCOD, %	TSS, mg/L	VSS, mg/L	VSS/TSS, %
Average	9.03	2345	5717	5226	89.4	763	546	72.3
Minimum	5.35	47	443	368	64.5	74	64	51.6
Maximum	12.48	3339	9350	8305	100	2550	1425	93.8

In an IC reactor, organic compounds are converted into biogas. Soluble organic substances with a low molecular weight such as sugar, alcohol and fatty acids are readily biodegradable. The data collected in Table 2 demonstrates the characteristics of effluents from IC reactor.

Table 2. Characteristic of effluents from IC reactor.

Parameter	pH	TCOD, mg/L	SCOD, mg/L	SCOD/TCOD, %	TSS, mg/L	VSS, mg/L	VSS/TSS, %
Average	6.78	945	377	41.7	578	482	83.6
Minimum	6.31	220	172	18.2	260	190	71.2

Maximum	7.48	2392	1533	78.2	1733	1350	92.8
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3 Results and discussion

3.1 COD conversion

Figure 1 shows the TCOD and SCOD in the wastewater influents into the anaerobic reactor and the percentage share SCOD into the TCOD.

Fig. 1. TCOD and SCOD in raw wastewater.

In 2016, the COD value in raw sewage was measured 282 times (Figure 1). The average annual COD was 5717 mg/L and amounted to 143% of the value assumed for the project. Results higher than the COD assumed for the project constituted 83% of the data. The highest value was recorded on 19th of August and it was 9350 mg/L, and the lowest was 443 mg/L (January 1st). 47% of results surpassed the average. Over the year, most of the results (72%) were in the range of 4500–7000 mg/L. According to the data presented by Oktem [6], the typical COD value in brewery wastewater was in the range of 200–6000 mg/L, but actual values exceeded this range. The value of soluble COD (SCOD) is of particular importance in the decomposition of organic substances in anaerobic reactors with a short HRT. The average annual SCOD was 5226 mg/L. The highest value was recorded on 19th of August – 8305 mg/L, the lowest was 368 mg/L (1st of January). SCOD higher than the average constituted 49% of results. Over the year, most results (80.0%) were listed between 4000–6500 mg/L. The soluble fraction constituted 89.4% of total organic compounds. The highest percentage share was 100% – on the November 13th, and the lowest (64.5%) on September 27th. Most results were between 90-95% and 85-90%, respectively 47.3% and 32.9%. In 2016, 225 results were analysed. The average annual TCOD in sewage effluents from the IC reactor was 945 mg/L. The highest result – 2392 mg/L – was recorded on 13th of October. That day, a low COD reduction (67%) was observed. The lowest COD was measured on January 3rd (220 mg/L). A high reduction of these parameters (82%) was achieved then. 93% of COD value after anaerobic treatment met the requirements of the regulation concerning the industrial wastewater discharge into the sewage system – 1400 mg/L. Treated sewage was dominated by values in the range of 500–1000 mg/L, which accounted for 60.0% of the results. The average annual SCOD value was 377 mg/L. The highest result – 1533 mg/L – was recorded on 13th of October, when the lowest SCOD reduction (75%) occurred. The lowest value was observed on January 3rd (172 mg/L). In

January, an increase SCOD values was noticed, with only 2 results below the average. The values from the scope of 250–500 mg/L were dominant, which accounted for 82.7% of all results.

Fig. 2. TCOD and SCOD in wastewater effluent from IC reactor.

The average annual percentage share of SCOD in the TCOD amounted to 41.7%. It was significantly lower than in raw sewage, which accounted to 89.4%. This confirms the effective operation of the IC reactor, which removed organic pollutants in a dissolved form. The highest share was recorded on January 3rd – 78.2%. It should be noted that the lowest share in the effluent from the IC reactor (18.2%) occurred on March 1st, when the SCOD/TCOD in raw sewage was 90%. Most results were in the ranges of 30–40% and 40–50%, which represented 30.7% and 26.2% respectively.

Fig. 3. TCOD and SCOD removal efficiency.

The average annual TCOD reduction was 83.7%. This result is representative of anaerobic digestion process in the IC reactor reported in the literature (over 80%). The minimum reduction occurred on 31st January (45.3%). At that time, the COD value in raw sewage was very low – 966 mg/L. For one of the highest COD values in raw wastewater (8108 mg/L), the reduction was 78.5%. The maximum removal efficiency (91.8%) took place on 7th of April, when the COD value in raw sewage was 6300 mg/L. The most frequent

interval was 80–90%, which concerned 76.7% of all the results. The reduction of COD lower than 70% was achieved only 6 times and the reduction higher than 90% was recorded 15 times.

The average decrease of SCOD was 92.9%. The minimum percentage reduction happened on 13th October (74.9%). The maximum reduction (96.1%) was recorded on 13th September. The dominant results were in the range 90–95%, which accounted for 76.8% of all the data. 11.9% of the results were recorded in the range of 95–100%. A greater reduction of the SCOD fraction was observed than in the case of the reduction of the total COD value.

3.2 Biogas production

Fig. 4. Biogas production vs HRT.

The average annual biogas production was 4089 m³/d. The highest result fell on 20th April (6653 m³/d), the lowest – 128 m³/d on 3rd May. In summer months, due to higher loads of organic pollutants (higher production), there were fewer low results compared to the rest of the year. The most frequent range was 4000–5000 m³/d (30.7% of records), 26.8% of data was in the range 5000–6000 m³/d. In order to facilitate the interpretation of the obtained data, figure 4 presents the average weekly biogas production in comparison with the actual HRT. In the literature, the HRT for an IC reactor accounts to 4-12h. The actual HRT was 11.9 h. The highest result was noted on 17th October and amounted to 53.8 h, the lowest 8.6 h was recorded on 21st July. One of the factors influencing the production of biogas is HRT. In theory, shortening the HRT should make the biogas production lower. The highest average weekly production of 5521 m³/d was recorded at HRT = 10.4 h. The data in Figure 4 do not support this thesis. However, from September to December 2016, increases HRT caused increases in biogas production.

The average annual OLR was 13.2 kg COD/m³·d. All OLR values were lower than the maximum value characterizing the functioning of IC reactors – 40 kg COD/m³·d. The highest OLR occurred on July 15th and amounted to 20.6 kg COD/m³·d, the lowest OLR – 3.0 kg COD/m³·d was recorded on October 9th. It should be noted that only 8 results exceeded the value assumed for the project 18.5 kg COD/m³·d. No significant correlation between biogas production and OLR was observed.

Fig. 5. Biogas production vs OLR.

Fig. 6. Biogas yield.

The biogas yield was 0.29 m³/kg COD_{in}. The highest value of 0.99 m³/kg COD_{in} was recorded on 15th October, while the minimum value on 20th January 0.04 m³/kg COD_{in}.

The dominant range 0.2–0.3m³/kg COD_{in} contained 52.6% of records. The second largest range was 0.3–0.4m³/kg COD_{in} (34.2% of the results).

Typically anaerobic treatment of brewery wastewater generates about 0.4–0.5m³ of biogas per kg of COD removed.

The average annual biogas yield was 0.33 m³/kg COD_{rem}. This value was slightly lower than the theoretical. Chen et al. [1] suggest that the AnMBR can achieve a COD removal higher than 98% while treating brewery wastewater, with a biogas yield level at 0.53 ± 0.015 m³/kg COD. The highest result was noted on 25th September – 1.25 m³/kg COD_{rem}, while the minimum result of 0.05 m³/kg COD_{rem} was recorded on 20th January.

The dominant records were in the range of 0.3–0.4m³/kg COD_{rem}, the share of which was 58.2%. The second most numerous range was 0.2–0.3m³/kg COD_{rem} (26.4% of records). On the other hand, the share of a range typical for brewing sewage 0.4–0.5m³/kg COD_{rem}, was 8.2%.

4 Conclusion

The conducted research confirmed the high efficiency of anaerobic processes for the treatment of brewing wastewater. The high content of dissolved organic compounds (89.4%) predestines this effluent for treatment in anaerobic reactors with a short retention time. The actual average HRT of 12.9h is close to the maximum time given in the literature. Biogas production is influenced by: the content of easily decomposable organic compounds in wastewater, process temperature, HRT, OLR. No correlation between biogas production and HRT or OLR was confirmed during the study. Unit biogas production was 0.29 m³/kg COD_{in} and 0.33 m³/kg COD_{rem}. The biogas produced in the digestion process is converted into heat.

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