Excess brewery yeast co-digestion in a full-scale EGSB reactor

G. D. Zupančič*, M. Roš*, M. Klemenčič**, M. Oset**, R. Marinšek Logar***

*Institute for Environmental Protection and Sensors, Department for Renewable Resources and Technologies, Beloruska 7, SI-2000 Maribor, Slovenia
(E-mail: *gregor.zupancic@ios.si*; *milenko.ros@ios.si*)
**Brewery Laško, Trubarjeva ulica 28, SI-3270 Laško, Slovenia
(E-mail: *mklemencic@pivo-lasko.si*; *moset@pivo-lasko.si*)
***Biotechnical Faculty, University of Ljubljana, Department for Microbiology and Microbial Biotechnology, Groblje 3, SI-1230 Domžale, Slovenia
(E-mail: *romana.marinsek@bf.uni-lj.si*)

Abstract
In the full-scale the anaerobic co-digestion of brewery yeast using granular biomass was studied. Full-scale operation with 0.7 % yeast concentration showed a 38.5 % increase in the biogas production and a 26.2 % increase in the organic loading rate, which resulted in an increase of the biomethane/natural-gas substitute ratio from 10 % to 16 %.

Keywords
Anaerobic digestion; biogas production; brewery yeast; brewery wastewater; microbial community structure

INTRODUCTION

The brewing industry produces large quantities of wastewater with a high concentration of degradable organic pollutants, which are ideal for the production of biogas. There are many conventional ways reported in the recent literature about how to successfully treat brewery wastewater, ranging from fluidised-bed bioreactors (Alvarado-Lassman et al., 2008), anaerobic sequencing batch reactors (Shao et al., 2008) to the mostly commonly used granular sludge reactors (Baloch et al., 2007) such as the Upflow Anaerobic Sludge Blanket (UASB) reactors or the upgraded versions, the EGSB (Expanded Granular Sludge Bed) reactors (Zoutberg and de Been, 1997). Such processes are well established and known; they appear in many varieties and are used in a range of temperature regimes as well (Connaughton et al., 2006). In recent years it has been the trend to devote more attention to energy production in these processes. As a result, the operators of such anaerobic treatment plants devote their attention to biogas production and its increase, mainly due to carbon-footprint reduction, as well as due to the economic benefits of biogas production. Bocher et al. (2008) showed an 8.1 % increase in methane production when treating secondary residuals in brewery-wastewater treatment, while Agler et al. (2010) showed a 7.6 % increase in methane production when treating primary sludge. In a study done by Neira and Jeison (2010) brewery yeast was already tested as a co-substrate in brewery wastewater treatment with no adverse effects; however the authors expressed concerns about long term operation and its effect on granular sludge. In our case study, Brewery Laško, one of the largest Slovenian breweries, produces approximately 400,000 m^3 of wastewater annually and has a Biothane's Biobed® EGSB reactor installed for the wastewater treatment, where the produced biogas is used as a supplement for natural gas. The brewery also produces 3000 tonnes of excess yeast annually, which has always been considered a secondary resource, although it has never been identified as an energy substrate. In the traditional way, waste yeast is dried and sold as an alimentary substrate to the food-processing industry. However, our research has shown that such processing is very energy demanding due to the large amount of natural gas required for the drying, and with ever-increasing energy prices such a conventional procedure is becoming more economically unsustainable. Waste yeast is high in organic solids' content and can be used as an additional substrate in a UASB reactor to produce more biogas and, consequently, save the natural gas that is used in the brewing process. This research paper looks at the possibilities of using waste yeast as an energy substrate to increase biogas production in brewery-wastewater treatment. In addition to previous studies done in this field (Neira and Jeison, 2010), in the presented study long term full scale digestion operation of brewery yeast in the wastewater/yeast was tested and the impact of yeast to microbial biomass was addressed.

MATERIALS AND METHODS

Full-scale operation

The brewery studied has a production rate of 100,000,000 litres of brew and is equipped with a wastewater-treatment facility, a Biothane's EGSB reactor that is 750 m^3 in size, with a 4000 m^3 equalization tank and a pre-conditioner (Figure 1). Subsequent treatment involves an aerobic municipal wastewater-treatment plant. Brewery wastewater has a pH between 4.5 and 5.8. In the pre-conditioning tank this wastewater is adjusted to pH 6.5. The wastewater flow to the equalization tank varies considerably with little influent at the weekends. The effluent from the equalization tank, i.e., the influent to the pre-conditioner and reactor, is less variable and more equally distributed over all of the weekdays. The average flow is 1150 m^3d^{-1}, the highest flow is 2400 m^3d^{-1}, and therefore the residence time in the equalization tank varies between 40 and 85 hours. The hydraulic retention time in the reactor varies from 7.5 to 84 hours, with an average of 15.8 hours. The reactor and influent temperature is 32–35°C, depending on the seasonal weather. The average COD, TS, VS and TKN of the waste brewery-yeast suspension throughout all the experiments were 277 gL^{-1}, 188 gL^{-1}, 177 gL^{-1} and 11.4 gL^{-1}, respectively. All of the available yeast was added to the wastewater flow. The average annual quantity of waste yeast is up to 0.7 vol. %, compared to the average quantity of wastewater. However, the waste yeast is not produced in the same way as the wastewater; therefore, a buffered release of yeast is absolutely essential. Since the wastewater flow is already unequal, it is relatively difficult to appropriately address this issue. The best way is to install a buffer tank with a size that corresponds to approximately five times the maximum daily yeast release and a carefully controlled release valve, which can be controlled manually or automatically according to the wastewater flow. In our case, we used two dormant tanks for the yeast storage, each 30 m^3, which were unused for several years. Also, more caution was applied to the equal flow to the pre-conditioning tank of the treatment plant (Figure 1).

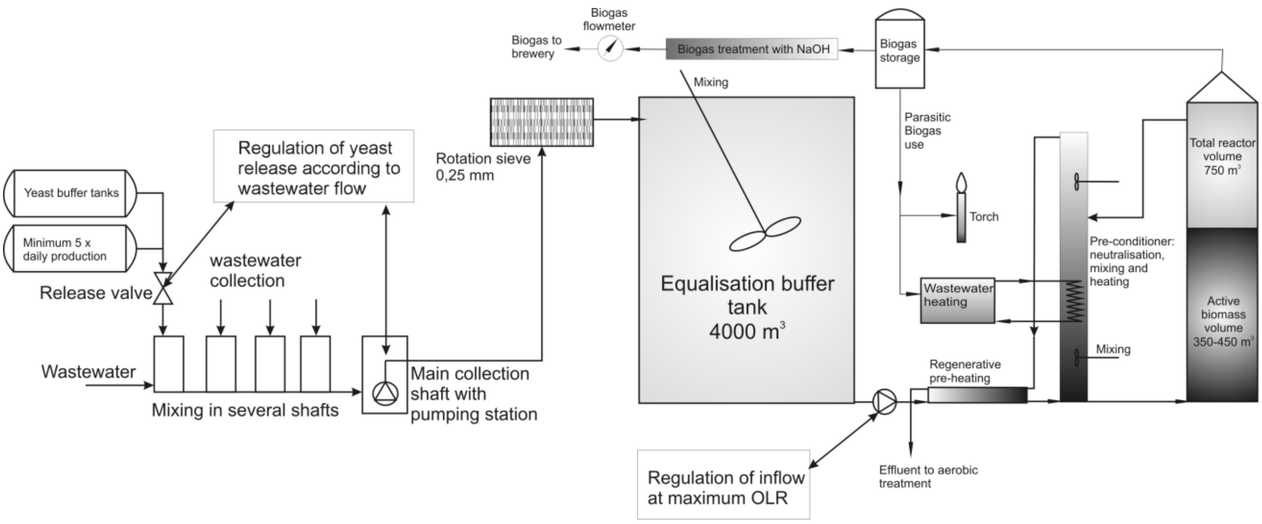

Figure 1. Full scale operation set-up.

We started the yeast addition with an adaptation period of 3 months, where we gradually increased the quantity of yeast to a maximum of 0.7 ±0.05 % (April - July 2010). After the 3-month period all of the produced yeast was added to the wastewater flow. We monitored the trial process for approx. 2.5 years to experience all of the conditions that occur during the operation of the treatment plant (up to October 2012). The COD, TS, nitrogen concentrations, wastewater and biogas flow were monitored daily. Throughout the experiments the total solids (TS), the volatile solids (VS) and the COD values were determined according to the Standard Methods Online (2010). The biogas and VFAs were determined by gas chromatography on Shimadzu, GC14A-TCD and Shimadzu, GC14A-FID, respectively. The pH was measured using a pH meter (Orion 520A). The microbial shifts were analysed using the T-RFLP method according to Stres et al. (2009). All the methods were kept under continuous statistical control.

RESULTS AND DISCUSSION

During the first two months of the adaptation period no statistically significant changes were observed, until the yeast concentration of 0.5 % was achieved. After reaching the full capacity of 0.7 % yeast, the wastewater plant was operated for an additional 26 months under all possible circumstances. Figure 2 shows the results of the full-scale operation for a year of operation treating wastewater

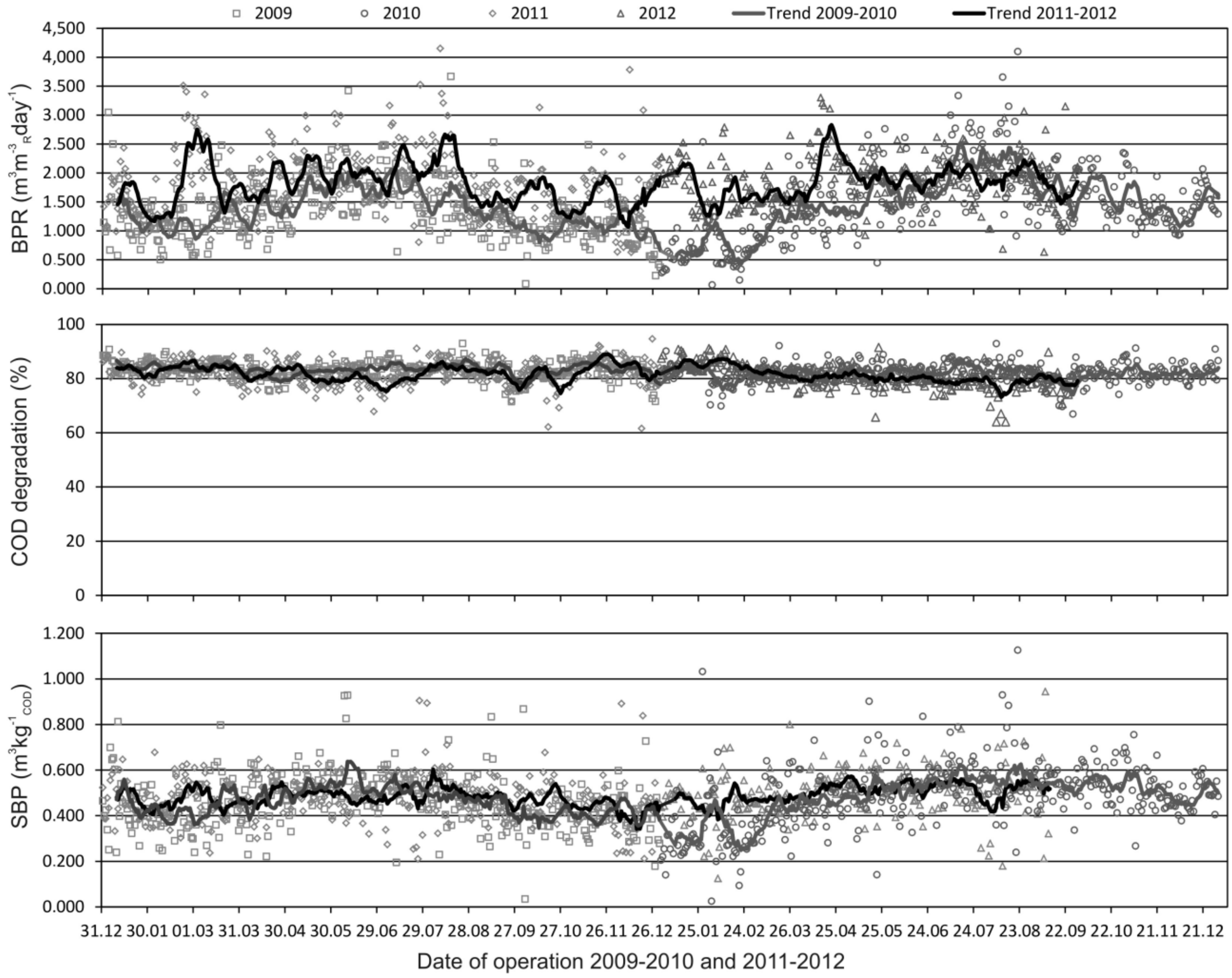

Figure 2. Results of full scale operation: Biogas production rate (BPR), COD degradation and Specific biogas productivity (SBP).

The annual wastewater flow were 399,720 m^3, 386,757 m^3, 392,592 m^3 for years 2009, 2010 and 2011, respectively and for year 2012 289,697 m^3 for first nine months. The influent COD ranged between 1270 and 5200 mgL^{-1} treating wastewater (year 2009 – May 2010) and between 1950 and 7460 mgL^{-1} treating 0.7 % yeast/wastewater mixture (May 2010 – October 2012). The effluent was ranging between 209 and 984 mgL^{-1} and 304 and 1340 mgL^{-1}, respectively. The COD degradation efficiency was 82.6 % treating wastewater and 82.1 % treating a yeast/wastewater mixture, which is statistically equal. The OLR was ranging from 0.46 to 11.1 $kg_{COD}m^{-3}d^{-1}$ and 1.24 to 12.75 $kg_{COD}m^{-3}d^{-1}$, respectively. The OLR increased by 26.2 %, and the biogas production rate (BPR) by 38.5 %. Specific biogas production (SBP) remained approx. equal without and with the addition of yeast at 0.475±0.052 m^3/kg COD inserted. The biogas composition throughout the operation did not change significantly, the methane content was 77.4±1.96 %; the CO_2 content was 21.9±1.99 %; and H_2S content was 0.68±0.19 %. No significant accumulation of VFAs was detected during the operation, and the concentrations of acetic, propionic and butyric acids in effluent never exceeded 31 mgL^{-1}, 12 mgL^{-1} and 5 mgL^{-1}, respectively.

The analysis of the microbial biomass showed that there were no significant shifts (only a 5 % dissimilarity) in the archaeal microbial community structure neither during the first 99 days of anaerobic digestion with full yeast quantity nor during the period of the next 189 days. The analysis of the microbial biomass also showed that there were significant shifts in the initial bacterial microbial community structure (32 % dissimilarity) already during the first 99 days of the anaerobic digestion with full yeast quantity. These results show that the bacterial community is perfectly adaptive to the new co-substrate and the major adaptation of the bacterial biomass is performed during the first 99 days after the start-up of the waste yeast addition to the reactor. The adapted bacterial biomass is perfectly able to hydrolyse and acidify the added new co-substrate.

CONCLUSIONS

The anaerobic co-digestion of brewery yeast and wastewater was studied. We found that such additional loading of the anaerobic process did not destroy or damage the operation of the full-scale system which was the apprehension of the equipment provider. In full-scale co-digestion at concentration of vol. 0.7±0.05% showed no negative impacts whatsoever. With the additional brewery yeast (0.7%) 38.5% increase of biogas production was detected, which resulted in an increase of the biomethane/natural-gas substitute ratio in the brewery from 10 % to 16 %.

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