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Evaluation of brewery waste and its reduction methods

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Abstract

The aim of this paper is the environmental impact due to brewing process which generate many kinds of wastes such as brewery spent grain, hot trub, residual brewer's yeast and waste water. The disposal of these wastes into the environment leads to damage to ecosystems owing to their composition rich in organic matter. This research is focused on evaluation of brewery waste before and after application of some methods used to minimize the pollution. There are measured parameters such as: pH, temperature, totals suspended solids (TSS), chemical oxygen demand (COD) and biological oxygen demand (BOD_5). Samples are collected from brewhouse, fermentation sector, barrel and bottling systems and also in end of pipe waste water effluent. The results of analysis show that the water discharged directly is out of the norms allowed by the Albanian authorities. The most contaminant part comes from the fermentation sector that has in itself high values of BOD (500-1500 mg/l), COD (650-2500 mg/l) and suspended solids (70-450 mg/l). Waste water from brewhouse, bottling and barrel systems contain significant presence of organic matters from the raw materials used, and a degree of acidity and alkalinity from the cleaning chemicals (pH varies from 3.4-9.8). The collected data were subject to statistical analysis (ANOVA) using the SPSS software (significance level at 0.05). Waste minimization is done by using clean-in-place (CIP) method, neutralization and treated tank for waste waters before it goes to discharge systems. The applications of these methods reduce the organic matters content approximately 40 percent.

Keywords: brewery; waste water; organic matter; COD; BOD.

1. Introduction

Beer is a fermented beverage with low alcohol content produced by malt, hops, yeast and water. It is obtained from starchy grain (generally barley), which undergoes steps such as malting, milling and wort preparation (mashing, clarification and boiling), with the addition of hops. Subsequently, the wort is inoculated with microorganisms, brewer's yeast, which is responsible for the formation of ethanol, CO_2 and many other byproducts by its fermentative metabolism. The fermented wort is then subjected to other processes such as clarification, maturation, filtration and beer packaging [4, 6]. During the manufacture of beer there are produced a number of substances which must be disposed of, prevented or reprocessed. These include in particular: waste water, spent grains and hops, hot trub, residual brewer's yeast, kieselguhr slurry, label residues, broken glass, dust from the raw materials, packaging residues, returned cans, glass and PET bottles, amongst others [15]. The brewery spent grain is generated (14–20 kg/hL of beer) during the lautering; the hot trub is generated (0.2–0.4 kg/hL of beer) during wort boiling and hops addition, by the coagulation and complex formation of high molar mass proteins and oxidized phenolic compounds; and the residual yeast during fermentation. In general, these wastes present a rich composition in organic matter and there are several components with significant nutritional value, such as fibres, carbohydrates, proteins and amino acids, vitamins, phenolic compounds and minerals [17]. For this reason, the chemical oxygen demand (COD) is high [9]. An indication of the BOD and COD levels of beer and different by products in brewery is shown in the Table 1. The brewing process is energy intensive and uses large volumes of water. In these processes, large quantities of water are used for the production of beer itself, as well as for washing, cleaning and sterilizing of various units and equipments used for beer production. The main water use areas of a typical brewery are brewhouse, cellars, packaging and general water use, which are of considerable importance both in terms of water intake and effluent produced [21]. An modern and efficient brewery will use between 4 and 7 L of water to produce 1 L of beer [8]. Water consumption is divided into 2/3 used in the process and 1/3 in the cleaning operations [19]. The quantity of brewery wastewater will depend on the production and the specific water usage. Brewery wastewater has high organic matter content; it is not toxic, does not usually contain appreciable quantities of heavy metals (possible sources: label inks, labels, herbicides) and is easily biodegradable [3]. Every brewery tries to keep waste disposal costs low whereas the legislation imposed for waste disposal by the authorities becomes more stringent [14]. The Table 2 shows typical composition of some physical and chemical characteristics of brewery waste water effluent.

Table 1. COD and BOD concentrations of brewery process units

Component	**COD (mg/l)**	**BOD (mg/l)**
Beer (lager tipe) (whole process)	150.000	80.000-120.000
Spent grain (brewhouse)	24.000	16.000
Yeast (fermentation)	210.000	140.000
Trub (brewhouse)	165.000	110.000
Kieselguhr (Filtration)	16.500	11.000

Source “European Brewery Convention, Manual of Good Practice” [7].

Table 2. Composition of brewery waste water effluent

Parameter	BOD (mg/l)	COD (mg/l)	SS (mg SS/l)	COD/BOD	pH	Water/Beer	Wastewater /Beer
Brewery waste water	6.000-18.000	11.000-20.000	2.000-4.000	1.5-1.7	3.5-9	4-10 mg/l	1.3-2 mg /l

Source “European Brewery Convention, Manual of Good Practice” [7].

Nowadays beer producers are paying attention to beer process and also are taking into account waste treatment (wastewater, spent grains, kieselguhr sludge and yeast surplus) as shown in Figure. 1. The brewery’s waste waters as a result of the materials that contain are in need of oxygen that’s why they deserve a high level treatment done either in the brewery itself or communal establishments. The fact that public establishments have higher costs means that it will be better for the breweries to carry out waste management and waste treatment by themselves [5]. This study aimed to characterize and determine the level of composition of wastewater effluent and its environmental impact due to brewing processes. The paper also shows the level of physico-chemical parameters of wastewater generated by each process of beer production and the final mixed wastewater before and after the application of some reduction methods.

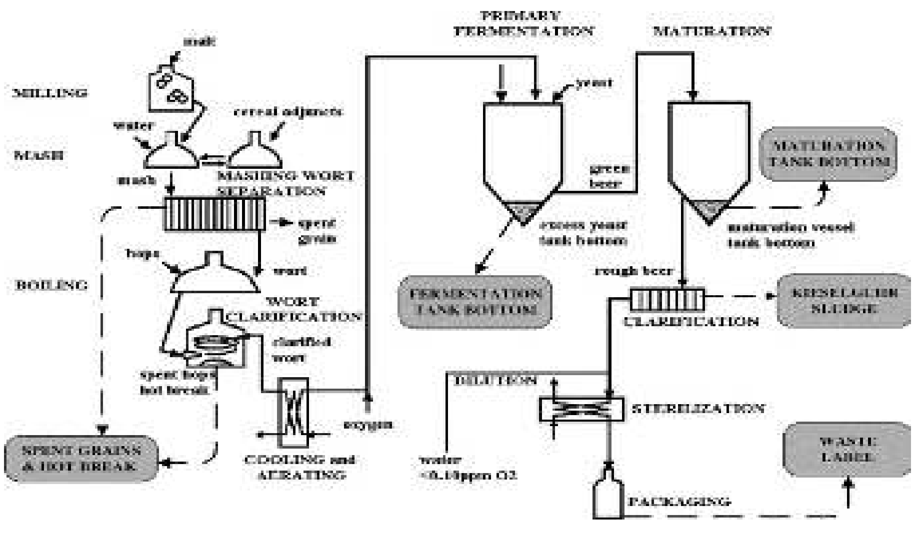

Figure 1. Brewing process and main waste [Source: 16].

2. Material and Methods

This study was conducted in a brewery in Tirana City during a period of five months (January to May). This is a period of normal beer production when the plant doesn't work in a high capacity. The production peak is usually during summer, for the seasonal nature of the product itself. The annual capacity production of this factory is approximately 70.000 hl of larger beer. Also non-alcoholic beverages are produced by this factory.

2.1 Sample collection

Samples of wastewater were collected from sewage drains during beer production process, directly from sinks discharges of respective brewing process stages (brewhouse, fermentation and packaging sectors). Prior to our study this brewery had not applied any treatment, pre-treatment or averages of wastewaters and they were directly discharged to the city sewage system (branch of Lana River).

Depending on operations performed and production cycles, the samples could be collected into different intervals of time. Sampling was also based on amounts and the composition level of wastewaters generated by brewery sectors. Brewhouse samples contain: wastewaters from rinsing a mash tub, wort boiler, filtration tub, and from the CIP process applied through the whole brewhouse system.

Samples of fermentation department contain: wastewaters from washing, rinsing, fermentation CIP, maturation, filtration tanks, and filtration systems as well as from the pipelines. Samples of packaging systems contain: wastewaters from beer bottling (wastewaters from bottle washing, tank of pasteurization beer, CIP) and from kegs system (wastewaters from washing, kegs pasteurization as well as beer unfit for consumption). These samples were collected in one liter sterile glass bottles and were transported directly to the laboratory for analysis [2].

2.2 Analytical techniques

Physico-chemical analyses were carried out within 24 hours of sample collection in the brewery laboratory, with the necessary preservation techniques adapted from Standard Methods. Brewery wastewater samples were analyzed for these parameters such as: Total Suspended Solids (TSS), temperature, pH, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5), according to Standard Methods for Examination of Water and Wastewater [2]. The TSS was determined gravimetrically by drying well homogenized samples respectively at 103°C - 105°C for 24 h [2, 5]. The wastewater pH was measured by using an electronic pH-meter after the proper calibration (with an accuracy of 0.01pH). The BOD_5 measurement was performed with the dilution method for five days. Dissolved oxygen was measured initially and after incubation, and the BOD is computed from the difference between initial and final DO according to standard method 5210 B [2, 1]. The COD concentration in the wastewater was determined with dichromate methods by close refluxing according to the standard method 5220D with an accuracy of 0.1 mg COD per Liter [2, 18].

2.3 Statistical Analysis

Analyses of wastewaters were conducted with 3 replications and there were calculated: mean ranges, standard deviations and confidence interval from data obtained. Graphs and statistical analysis of results were performed by using the computer software SPSS. The statistical analysis of data was carried out with one-way analysis of variance (ANOVA). The significance level was 0.05. Differences between mean values were analyzed with the Tukey test.

3. Results and Discussion

During this study, there were observed differences in composition of wastewaters generated from processes of beer production. There were analyzed 50 different samples from each brewery sectors with 3 replicates. The Table 3 shows physicochemical results obtained from wastewater composition analysis of brewhouse and fermentation departments. The highest pH values of wastewaters from brewhouse and fermentation sectors were

9.8-9.85, caused by discharging of caustic soda used as cleaning agents during CIP process. Wastewater discharge of fermentation sector presented the lowest pH values at 3.4 due to the usage of cleaning and disinfection agents.

Table 3. Wastewater composition of brewhouse and fermentation departments

Sectors	Statistics	pH	TSS(mg/l)	COD(mg/l)	BOD_5(mg/l)
Brewhouse	**min**	4.94	78	697	480
	max	9.8	365	2054	1525
	Mean	6.94	160.07	1388.57	965.90
	St.dev*	1.47	81.40	443.65	329.33
Fermentation	**Min**	3.4	56	710	579
	Max	9.85	486	2570	1680
	Mean	6.23	235.90	1544.03	1176.47
	St.dev	1.72	144.28	546.11	348.99

*St.dev-standard deviation;

The maximum values of total suspended solids in brewhouse and fermentation sectors ranged from 365-486 mg/l due to brewer's spent grain, hot trub, residual yeast and kieselguhr slurry discharged to wastewaters. The highest concentrations of COD and BOD determined in wastewaters of brewhouse were (2054 mg/l and 1525 mg/l, respectively) originated from discharges of wastewater of mash tube, wort kettle and hot trub. The highest level of COD and BOD (2570 mg/l and 1680 mg/l respectively) were noted in fermentation department due to the discharge of yeast, maturation sediments, beer and kieselguhr slurry. The physic-chemical results of wastewater composition analyses of some bottling lines are presented in Table 4.

Table 4. Wastewater composition of packaging sector

Parame-ter	Statistics	non alcoholic	PET line	line washing	glass line	kegs line	cans line
pH	mean	4.72±0.12	6.38±0.12	9.23±0.09	6.32±0.08	7.22±0.55	6.06±0.12
	St. dev	0.15	0.10	0.08	0.08	0.97	0.11
TSS (mg/l)	mean	93.5±10.05	74.33±6.23	107.33±7.36	249.33±16.18	222.0±8.16	196.08±29.68
	St. dev	12.57	5.51	6.51	14.29	7.21	52.45
COD (mg/l)	mean	797.67±153.2	766.0±17.09	615.0±14.8	1009.0±23.22	1866.0±36.8	1184.92±152.8
	St. dev	191.46	15.10	14.80	20.52	32.60	152.82
BOD (mg/l)	mean	561.83±85.65	605.00±8.54	247.67±12.6	534.33±10.14	1516.33±50.	787.33±91.37
	St. dev	107.04	7.55	11.15	8.96	44.61	161.48

As it is noted in Table 4, the pH values of packaging wastewaters varied from 4.7 to 9.3 related to the performed process. Discharges effluent of non alcoholic beverages reported low pH value due to the nature of product itself (maximum pH value of the final product was about 3.3). Wastewaters from line washing station were characterized by high pH values. This wastewater effluent contained considerably higher quantities of washing and disinfecting agents compared with other discharges. The highest concentration of COD and BOD were determined on wastewaters originated from kegs line. The increasing of those parameters was mainly caused by the beer discharge from returned barrels. In addition, physico-chemical analyses were conducted on wastewaters originated from the whole production plant, which contained wastewaters effluent from sectors mentioned above and those of administrative and factory buildings. Samples were collected to the end of pipeline of brewery discharge prior to join the municipal sewage system. Table 5 shows high levels of organic load contained in wastewaters of entire brewery. The mean value of TSS was higher than those reported from each production departments. Of course that this wastewater definitely requires a treatment before discharged to the branch of Lana River. Waste water treatment is more expensive than waste water prevention. From this point of view, the prevention of waste water is of particular significance [15]. During this study there were applied some technical alternatives to reduce the water consumption and consequently brewery waste production. The CIP method was used as an efficient cleaning method to save water, energy and chemical agents. There were also used some separation techniques for yeast, spent grains, kieselguhr slurry and solids waste of bottling sectors. Yeast and spent grains are used as livestock feed. The disposal routes of kieselguhr sludge are into agriculture and recycling [10]. Brewery wastewaters treatment was carried out through mixing and balancing tank for daily discharge. This tank was able to equalize the daily output, to collect the output and make it more consistent and to neutralize it [15, 20]. Daily output of entire brewery wastewaters was collected to a balancing tank and discharged to the municipal sewage after treatment. Table 5 presents the composition of treated wastewaters effluent before dumped to the wastewater network. The results noted reduction of organic matters content about 40 percent as results of the implementation of separation and treatment techniques. These results indicate that the wastewater after treatment was neutralizing (pH value ranged from 6.7-7.35). Mean value of TSS content after treatment was reduced to approximately 30 percent due to sedimentation in the mixing tank.

Table 5. Physico-chemical parameters of wastewaters from whole plant before and after treatment.

wastewater	Statistics	pH	TSS mg/l	COD mg/l	BOD_5 mg/l
The whole plant	**min**	4.40	198.00	1327.00	828.00
	max	9.30	412.00	2176.00	1502.00
	Mean	6.90	315.20	1845.93	1153.00
	St.dev	1.87	69.57	294.47	221.58
Mixing and balancing tank	**min**	6.70	150.00	937.00	532.00
	max	7.35	283.00	1232.00	998.00
	Mean	7.07	220.87	1121.53	792.67
	St.dev	0.20	50.22	93.80	142.44

Based on the fact that effluent from the brewery plant is regarded as a biodegradable industrial wastewater and the COD concentration of brewery effluent is more than 800 mg/L, it would be more adequate using anaerobic digestion technology to achieve a better reduction of organic load [11].

Table 6. Ratio of mean percentage content of BOD_5 in the total COD

Ratio	Brewhouse	Fermentation	Packaging	Whole Plant	Mixing and balancing tank
BOD_5/COD	69.56%	76.19%	67.76%	62.46%	70.68%

Value of BOD_5/COD percentage presented in Table 6 were in accordance with other studies which suggested that organic component in brewery effluent (expressed as COD) is generally easily biodegradable. This is illustrated by the relatively high BOD/COD ratio of 60% –70% [12, 13].

Table 7. Results of Tukey statistical test ($\alpha = 0.05$). Degradable organic compounds depending on sites of wastewater discharges

	Brewhouse	Fermentation	Bottling	Whole plant	After Treatment
BOD					
Brewhouse		0.0686	0.019	0.3125	0.3914
Fermentation	0.0686		0.0001	0.9992	0.0013
Bootling	0.019	0.0001		0.0002	0.9387
Whole plant	0.3125	0.9992	0.0002		0.0149
After Treatment	0.3914	0.0013	0.9387	0.0149	
COD					
Brewhouse		0.5901	0.0205	0.0057	0.2501
Fermentation	0.5901		0.0001	0.1474	0.0133

Bootling	0.0205	0.0001		0.0001	0.9891
Whole plant	0.0057	0.1474	0.0001		0.0001
After Treatment	0.2501	0.0133	0.9891	0.0001	

The value lower than α = 0.05 indicates statistically significant difference in biodegradability between particular types of wastewaters. The value of statistics above α = 0.05 indicates a lack of significant difference in biodegradability.

The results of statistical analysis show no significant differences in the quantity of BOD in brewhouse wastewaters effluent, and those of the whole plant and after treatment (Table 7). No significance difference is presented in BOD_5 quantity of fermentation sector and the entire brewery (Table 7). The statistical results in Table 7 show no significance difference of COD quantity between wastewaters after treatment and those of brewhouse and bottling sectors.

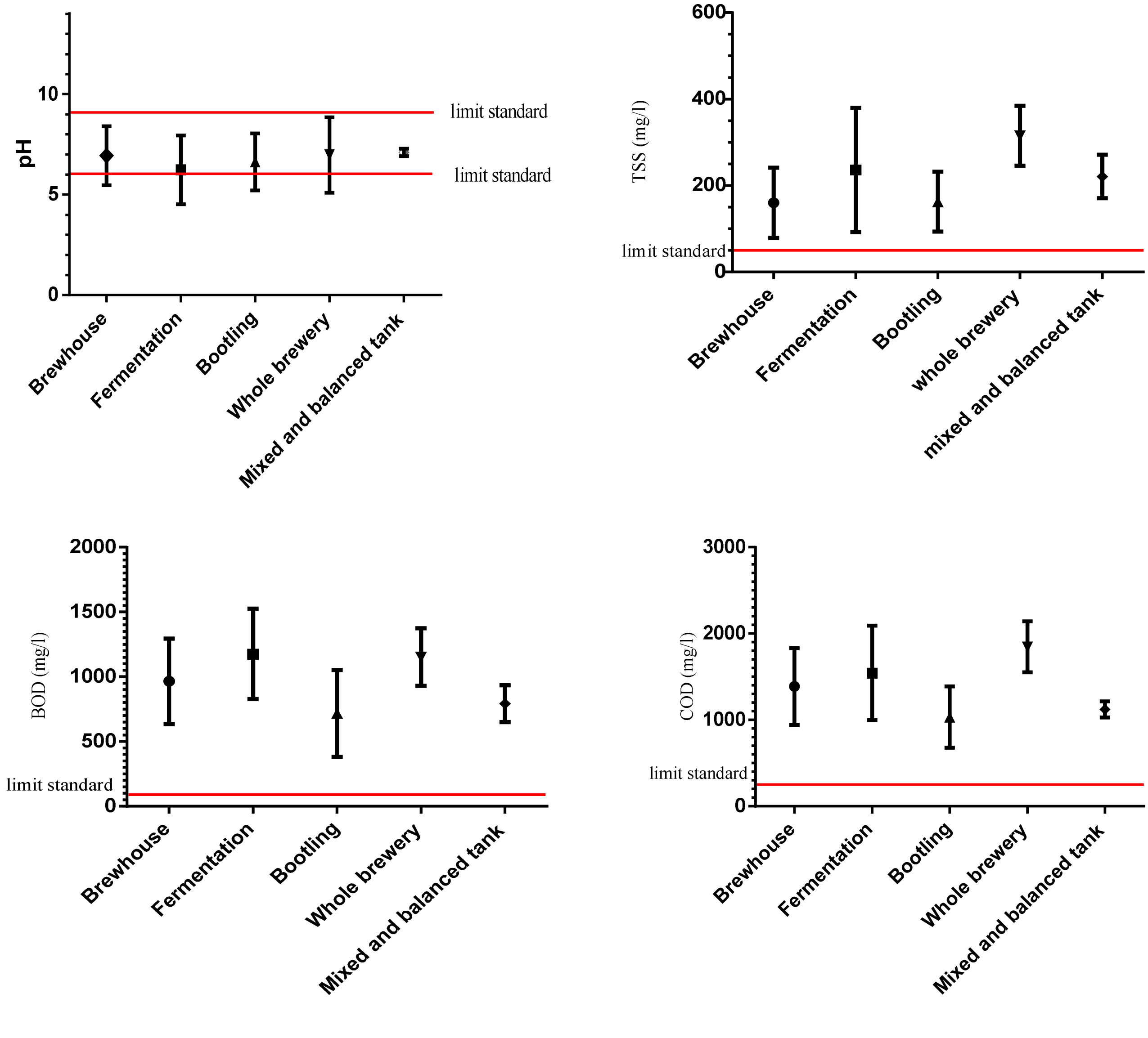

Figure 2. Statistical results of physico-chemical parameters of wastewaters originated from different sites compared with Albanian standard of waste disposal.

Figure 2 and the results presented in tables above show that wastewaters effluent originating from each production department before and after treatment, did not meet the discharge limits for brewery wastewater disposal to water bodies according to the Albanian discharge standards (pH=6 to 9, TSS = 50 mg/L, BOD_5 = 50 . mg/L, COD = 250 mg/L) [22]. Only pH value measured after the mixing and balancing tank is within premised values (6 to 9).

4. Conclusion

Wastewaters effluent of brewhouse, fermentation, bottling and whole brewery contains high levels of TSS, BOD_5 and COD. During production processes pH varied from 3.4 to 9.8. This study allows us to consider easily biodegradable the effluents generated in brewery. The ratio of BOD_5/COD expressed in percentage is 62%-76%. Wastewaters discharged from the entire brewery achieved about 40 percent reduction of organic load after the application of some prevention and treatment methods. Despite the treatment, wastewaters discharged directly in the municipal sewage system are more contaminated then norm and it is beyond discharge limits allowed by the Albanian authorities. In terms of water management, strict legislation favors a reduction of water consumption and wastewater production in order to reduce the volume to treat [10]. Based on other studies as well as the current study, we suggest anaerobic system followed by aerobic as the most efficient method for brewery wastewaters treatment. Nowadays challenge of brewery treatment is reduction of waste amount on the environment, which does not compromise the beer quality.

5. References

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