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Characterisation of effluent discharges from edible oil producing industries in Bulawayo, Zimbabwe

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Abstract

The discharge of poor quality effluent by edible oil industries in the City of Bulawayo poses a threat to public wastewater treatment plants and water resources alike. Snap and composite samples of the liquid effluents were collected manually from manholes and discharge outlets from the two edible oil producing plants for a period of six months and analysed using standard procedures. The effluent did not meet the regulatory quality standards established by the municipality. The effluent was characterized by high values of soap, oil and grease (SOG), chemical oxygen demand (COD), sulphates, total dissolved salts and turbidity. Although one of the industries pre-treats its effluent before discharging it to the sewer, further treatment of the effluent is still necessary to meet regulatory standards. One of the industries discharges some of its very poor quality effluents into dumping pits.

1 Introduction

Industrial wastewater discharges into the municipal sewers contribute quite significantly to the pollution load of municipal sewage handling systems [1,2]. Section 8 of the Bulawayo by-laws allows industries to discharge any quantity of waste water into the municipal sewers provided sufficient notice is given to Council and provided the quality of waste to be discharged is within the quality limit range as set out in the standards [3]. The monitoring activities of the City officials show that most process industries fail regularly to comply with the City's set standards [4]. This is because most industries in the City do not pre-treat their liquid effluents before they are discharged into the City sewers, which is the practice in most developing economies.

The absence of pre-treatment facilities is due largely to the absence of enabling and enforced regulations in all the urban centres in Zimbabwe until in recent years. As a result of the guidelines contained in the 'Discharge and Disposal (Water Pollution) Regulations, 1999', [5] a number of urban councils have adopted or are in the process of adopting the 'polluter pays principle'. Here the producer of any pollution should pay the full cost of treatment to reduce pollution loads to levels which will not cause environmental damage or loss of beneficial use to others, together with the cost of monitoring and management. The City of Bulawayo is in the process of setting up a tariff structure so that it can implement this principle. This will not only put a huge financial burden on the industry but a perpetual offending industry risk being closed. The implication of this is that an industry that generates substantial effluents should take measures to reduce its pollution load before ultimate discharge to the sewage system.

A first step to pre-treatment is to characterise the effluent from each industry with the main aim of setting up a pre-treatment facility. In the course of our studies we found out that most industries do not regularly determine the pollution characteristics of their liquid effluents. This paper presents the results of the physico-chemical characterisation of effluents from two edible oil producing plants in the City of Bulawayo. This is a part of the investigation being carried out in the Department of Chemical Engineering at the National University of Science and Technology to assist both the industries and the City authorities to enhance the management of industrial effluents in the city. To the industries to enable them set up the pre-treatment facilities and to the City, to enable it set up a tariff system for industrial effluents.

2 Effluent water generation and management in the two plants

There are two main edible oil refineries in the City of Bulawayo, and one of them houses a soap production plant. The plants produce a combined average of $2.8x10^3$ t of oil per month, utilizing approximately $32m^3$ of water in the process. The soap production unit saponifies an average of 150 t of fat per day. Both plants extract most of their vegetable oil from cottonseeds and soya beans. The process of extraction involves seed preparation, mechanical and solvent extraction and minute quantities of wastewater are generated in these processes. Most of the effluent is generated in both plants in the refining and the washing process after neutralization. The soap stock produced during the neutralization process in refinery 1 is either acidulated and the fatty acids and oils used in stock feeds manufacture or sold as a raw material for soap production. In the other plant, (refinery 2) the soap stock is used as a raw material in soap production. Insignificant amounts of wastewater are generated from the other stages of refining and are mostly housekeeping wash water. The other significant source of wastewater comes from the cooling towers and the acidulation of soap stock with sulphuric acid.

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2.1 Refinery 1

In this plant the effluent comes from the acid splitting of soap stock and refinery section mostly wash water. This effluent passes through a pre-treatment plant before being discharged into the city sewers. The pre-treatment process involves acidification, coagulation and flocculation using alum, and a polymer, pH correction and gravity settling.

2.2 Refinery 2

There are three sources of effluents from this plant and they are house keeping and cooling tower waste water, that from the oil refinery and soap lyes from the soap making plant.

The waste water from housekeeping and from the cooling towers is passed through an interceptor where the floating oils and suspended solids are removed before being discharged into the city's sewage system. The waste water from the oil refinery and the soap lyes from the soap making plant are normally acidified and the resultant acid water is dumped into pits. The dumping of soap lyes and soapy water or acid water into pits is practised because of the inability of the municipality treatment works to cope with the quantity and quality of effluent generated. The dumping of this waste is posing a serious threat to groundwater and as well as contaminating the land. Currently the company is in the process of implementing a project to pre-treat this effluent to make it suitable for discharge into sewer. Mitigation measures to solve the problem of the dumpsites are also under consideration.

3 Methods and materials

3.1 Wastewater sampling

Manual and systematic sampling was employed, and the sampling programme was divided into two phases. In the first phase snap samples were collected over an 8-hour shift after an interval of 8 days. This phase lasted for two months and at least five snap samples were collected on each shift and composited to give the time interval composite sample. In the second phase, one snap sample was collected once a week for four months. Samples were collected from the manhole, except for the lyes and wash water generated in refinery 2. These were collected either from the process discharge outlet or from the bulk storage tanks.

3.2 Wastewater characterisation

Samples were collected and analysed within 24 hours of collection and preserved by refrigeration prior to analysis. However, parameters such as temperature, conductivity, pH, colour and odour were determined on site. The methods of analysis adopted were the standard procedures, Standard Methods, 20th edition[6]. The only parameters measured in this work are those considered necessary for characterisation of waste water from vegetable oil processing industries as outlined in Bailey's Industrial oil and fat products' [7]. In the second sampling phase, only the conventional pollutants affecting the performance of public treatment works were considered as the phase was intended to confirm the earlier results.

4 Results and discussion

4.1 Refinery 1

Characterisation studies revealed that the effluent has a high organic and sulphate load (Table 1). The organic matter consisting mainly of soap, oil and grease (SOG) and suspended solids are the major contributors to the high COD levels. However there was no direct correlation between the COD values and the SOG values, because the suspended solids (SS) have a significant oxygen demand. The suspended solids are mostly generated during de-gumming process. Even if some of the lecithin is removed some of it inevitably ends up in the effluent. Average COD, SOG and sulphate levels of 5155mg/l, 1271 mg/l and 3721mg/l respectively were obtained during the first phase of sampling. This could result in the clogging of sewer pipes and pumps and the corrosion of sewer lines [7]. The high COD levels can create shock-loading problems for wastewater treatment plants, [8]. However, with the plant located about 600m from the public treatment works, it was observed that corrosion of the sewer lines has been minimal due to the rather low residence time of the effluents in the pipelines. An average total dissolved solids (TDS) of 3270mg/l was obtained in the first phase of monitoring. This is due to the use of inorganic salts in coagulation, pH correction and the sulphates from acidification and acid splitting. There was a small variation in the temperature and pH of the effluent (Table 2).

The effluent did not meet the regulatory standards set by the municipality (Appendix 1) in terms of the COD, sulphates, conductivity and SOG levels. The temperature was within the stipulated limits. The average pH was close to the lower discharge limit of 6.5, and was below it in some instances. The level of SS was above the regulatory standard in most of the instances. Average chloride and alkalinity levels of 112mg/l and 605mg/l respectively were noted. A significant drop in the COD and SS levels was observed during the second monitoring phase (Table 3). This is because a screen was installed prior to the equalisation tank between the sampling phases based on our observation. The reduction in the COD levels was partly due to the reduction in the level of suspended solids and partly due to reduction in the amount of oil refined and soap stock acidulated. However, there was no significant change in the TDS levels largely because these are due to the use of inorganic salts and sulphuric acid during pre-treatment. The pH was within the stipulated limits during the second phase although there was a slight increase as compared to the first phase. Although the level of SS was below the regulatory limit for the greater part of the second monitoring phase, the COD and TDS levels were still above the stipulated limits.

Table 1: Phase 1 results for refinery 1

Parameter {mg/l except when stated}	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
pH (pH units)	6.81 5.30	6.72 9.70	6.97 8.50	6.49 2.39	6.46 12.03	6.99 6.91	6.64 11.27
Temperature (°C)	30.9 26.3	21.8 23.3	25.9 25.7	28.6 27.8	33.4 35.3	25.1 23.4	29.6 32.90
SS	819 4960	68 2850	362 2855	6090 16360	4696 4760	161 1340	1084 7910
COD	3300 23960	4960 45600	5685 15605	5450 12495	7667 65771	859 2753	8167 40600
SOG	1000 2300	900 4400	1200 2000	2600 4000	1700 4200	50 120	1450 2100
Sulphate	1790 45	1200 2960	1700 1575	8130 12800	3500 4760	229 170	9500 2600
TDS	1810 1324	1383 5775	3271 2170	5710 9140	3515 4390	1916 570	5284 3010
Conductivity (uS/cm)	3620 2643	2763 11545	6540 4335	11410 18290	7035 8790	3830 1139	10570 6020
Salinity (ppt)	1.9 1.8	0.9 3.5	1.3 2.7	6.5 10.8	3.4 5.1	2.0 0.6	3.0 3.2
Turbidity (FAU)	1034 7840	118 3275	362 5015	8130 41080	2482 3496	229 2110	1809 9300
Chloride	130 7840	5 100	38 80	150 465	215 130	215 30	48 100
Alkalinity	350 195	384 3783	425 1080	1325 3300	573 4080	573 468	593 2100

Note: 1. Results for the effluent are shown above those of the raw effluent
2. The pH and temperature are averages of the snap samples

Although the effluent does not meet the regulatory standards the performance of the pre-treatment plant is however, satisfactory (Table 2). The plant achieved approximately a 70% and 80% reduction in the COD and SS levels respectively (Table 1). However the efficiency of the plant in reducing the SOG levels is low, about 50%, indicating that substantial amount of the emulsified oils went through the pre-treatment plant unaffected. It has been suggested that higher levels can be obtained when effluents containing SOG is treated by enhanced dissolved air flotation (DAF). However, its application has not proved to be satisfactory in meeting regulatory standards [9]. Consequently it is not being recommended as a one stage treatment unit for this plant. A biological treatment process in addition to the existing physical treatment unit may be the preferred system to treat this waste.

Table 2: Range and mean of the values obtained in phase 1 for refinery 1

Parameter {mg/l except pH or when stated}	Range of values Influent	Effluent	Mean of values Influent	Effluent
pH	2.3-12	6.0-7.2	8.01	6.72
Temperature(°C)	23-35	21-35	27.8	27.9
SS	800-16000	68-8000	5862	1897
COD	2500-65800	880-13550	29540	5155
SOG	2000-4500	1600-2600	2731	1271
Sulphate	40-12800	1200-7100	3559	3721
TDS	570-9000	1300-7000	3768	3270
Conductivity(uS/cm)	1000-18000	3000-14000	7537	6538
Salinity(ppt)	0.5-10.8	2.0-5.0	3.9	2.7
Turbidity(FAU)	1700-41000	118-17700	10302	2023
Chloride	10-470	5-315	138	112
Alkalinity	60-4800	220-1600	2144	603

Table 3: Phase 2 results for refinery 1

Parameters in mg/l{except pH}	December range	mean	January range	mean	February range	mean	March range	mean
pH	6.15-8.61	6.97	7.00-8.41	7.83	6.50-8.9	7.45	8.0-10.20	9.45
TDS	5100-13300	10200	9000-10600	9947	3000-5200	3850	1900-4000	2900
COD	2100-3514	2822	2100-2600	2333	2400-2900	2628	2000-3400	2650
SS	80-320	253	160-400	293	200-520	300	251-819	463

4.2. Refinery 2 housing a soap factory

4.2.1 Wastewater from house keeping wash and cooling tower

The results from these sources indicate that the quality of the effluent meets municipality regulatory standards (Table 4). The major parameters pH and SS were within stipulated limits. The COD of this effluent was above the stipulated limit during the initial monitoring period and showed a gradual decline below the discharge limit during the last monitoring phase. However, the conductivity was above the stipulated regulatory limit (Table 5). There was no significant change in the pH and SS levels during the second monitoring phase (Table 6). However there was a rise in the COD level as compared to the first phase rising above the stipulated limit. This was due to the overflow of the soap lyes from the dumping pits into the storm drain. Discharge of this overflow into the storm drain is prohibited because the drains discharge directly into natural watercourses.

Consequently the effluent was pumped into the interceptor and discharged to sewer. Good housekeeping and avoiding spillage can help reduce the amount of effluent generated.
Cooling towers accounts for over 40% of the effluent generated via this source. Installation of a ball valve system and ensuring that the level of water in cooling towers is set to avoid overflowing was recommended.

4.2.2 Wastewater from oil refinery

The analysis of wastewater from the oil refinery shows that the effluent has a variable organic load and a low inorganic load (Table 7). The data indicate very high COD and SOG load especially at the initial days of the investigation. This was due to operational difficulties as the centrifuges were poorly set resulting in poor separation. The COD was found to be function of the type of seed being processed and this explains the low value on day 3. The COD and SOG values suggest that there is a need to treat the effluent prior to discharge into the sewers. An average sulphate content of about 3000mg/l was noted but its origin could not be accurately established. There was a small variation in the pH and chloride levels as compared to other parameters (Table 7). The SOG content can affect the level of SS in the washwater because oils can be measured as SS depending on the temperature and physical state of the sample. Observation indicates that optimising the centrifuge settings can reduce the SOG levels in the washwater, which contributes to high refinery losses. Segregation of the washes with a high SOG content from the washes with a low SOG so that the free fatty acids in the waste could be recovered thereby reducing the organic load in the effluent.

Table 4: Phase 1 results for refinery 2 housekeeping effluent

Parameters {in mg/l unless stated}	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
pH(pH units)	11.44	10.78	6.94	9.54	8.33	9.5	8.2
Temperature(^{0}C)	31.3	30.5	27.5	28.7	28.3	28.9	28.4
SS	430	516	290	556	209	469	330
COD	5100	2432	1019	1755	774	1306	1430
Alkalinity	630	566	217	440	697	630	580
Turbidity(FAU)	606	741	427	752	312	621	472
Conductivity(Us/cm)	1847	1441	711	808	388	1210	980
TDS	924	721	350	399	194	608	495
Salinity(ppt)	0.3	0.7	0.3	0.4	0.2	0.6	0.5
Phosphates	63.0	132.0	2.4	40.5	23.0	11.3	9.8
Chloride	50	81	65	68	70	63	58
Sulphate	540	94	21	75	190	80	73

4.2.3 Wastewater from soap making

The results indicate that this effluent also has a high organic and inorganic load (Table 8). The effluent is highly alkaline, with an average pH of 13 and average total alkalinity of 59216mg/l. The major inorganic components are chlorine, phosphates and sulphates. The waste is characterised by high salinity with an average chloride content of 16625mg/l. The average phosphate and sulphate content are 2557mg/l and 3250mg/l respectively. The SS are mostly due to residual soap and to some extent oils and range from about 1020mg/l to

3900mg/l. There appears to be a direct correlation between the SOG and the COD levels. The samples were diluted to reduce the interference due to chloride ions. Therefore pre-treatment of the effluent prior to discharge is a necessity. The pre-treatment should aim to reduce the organic load due to residual soap, oils and glycerol. Reduction of the inorganic load (chlorides, sulphates and phosphates) requires advanced treatment methods. Physical treatment of the effluent to make it amenable for biological treatment requires acidulation and pH control which all utilise inorganic chemicals. Therefore reducing the inorganic load may have to be carried out in more than one stage.

Table 5: Range and mean of results obtained for phase 1 housekeeping effluent

Parameters {in mg/l unless stated}	Range of values	Mean of values
pH(pH units)	6.4-11.5	9.2
Temperature(^{0}C)	24.8-31.3	29.1
SS	201-628	400
COD	774-5100	1973
Alkalinity	126-800	537
Turbidity(FAU)	293-894	562
Conductivity(Us/cm)	353-1847	1055
TDS	176-924	527
Salinity(ppt)	0.2-0.7	0.4
Phosphates	2.4-191.0	40.3
Chloride	44-88	65
Sulphate	21-540	153

Table 6: Phase 2 results for refinery 2 housekeeping effluent

Parameters {in mg/l except pH}	December		January		February		March	
	range	mean	range	mean	range	mean	range	mean
pH	11.0-12.5	11.6	9.0-12.1	10.9	10.5-11.9	11.5	6.6-12	10.3
COD	600-2500	1442	1450-3400	2773	1700-4000	2742	1300-3900	2704
SS	250-320	292	200-340	265	200-320	263	260-310	283

5 Conclusion

The quality of the effluent produced by the edible oil refineries in Bulawayo does not meet municipality regulatory standards for discharge into sewers except for the housekeeping effluent discharged by refinery 2. The effluent was characterised by high conductivity, turbidity, COD, SOG, chloride, phosphate and sulphate levels. Although one of the refineries does physical treatment on its effluent, the quality of the effluent still does not meet regulatory standards in terms of the conductivity, COD, SOG and sulphate levels. Further treatment is required to meet regulatory standards. The disposal of high strength refinery and soapmaking effluent into pits should be discontinued as it could lead to the contamination of water resources and the land. Therefore pre-treatment of the effluent and remediation of the existing pits is a necessity. No heavy metals were

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detected in the effluent as expected from both refineries. Although phenols were detected in the refinery effluent in some instances, its levels were below 0.07mg/l.

Table 7: refinery 2 washwater results

Parameter (mg/l except pH or when stated)	Range of values	Mean of values	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
pH	6.23-12.41	10.38	12.41	6.23	10.58	11.59	10.82	10.66
Temperature(°C)	24.3[1]-53.0	44.6	24.3	53.0	49.2	48.9	46.3	45.8
SS	703-15980[2]	4649	5940	15980	1150	1476	703	2600
COD	999-996600	269039	323800	996600	999	6791	10043	27600
SOG	100-25000	7983	4500	25000	100	3300	1000	14000
Sulphate	24-8000	3000	8000	24	275	1100	1500	7100
TDS	385-9855	2452	9855	530	385	2240	611	1092
Conductivity(uS/cm)	770-19700	4892	19660	1055	770	4470	1216	2180
Salinity(ppt)	0.4-2.4	0.9	0.6	0.4	0.4	2.4	0.6	1.1
Turbidity(FAU)	723-15600	5601	9850	15600	2236	2215	723	2984
Chloride	5-110	35	20	5	5	40	30	110
Phosphates	300-1300	810	940	1200	440	1300	40	940
Alkalinity	310-17120	3766	17120	310	285	980	1000	2900

Note: 1.The washwater was collected from the storage tank after cooling. The general temperature range is from 45-53°C.
2. Oils can be measured to some extent as SS depending on the temperature and physical state of the sample.

Table 8: Results for refinery 2 soapmaking effluent

Parameters, mg/l unless stated	Range of values obtained	Mean of values	Day 1	Day2	Day 3	Day 4
pH	12.2-13.6	13.08	13.45	13.57	12.23	13.09
Temperature	23.3-62.3	37.7	35.0	30.1	62.3	23.3
SS	1020-3900	2510	1390	3900	1020	3730
COD	75600-216325	143337	153500	118250	75600	226000
Alkalinity	5650-97000	57912	5650	97000	54000	75000
Turbidity	2500-3700	3044	3130	2500	2847	3700
Conductivity	50575-20200	105144	50575	202000	97100	70900
TDS	25300-101100	52600	25300	101100	48600	35400
Phosphates	270-5500	2167	1000	5500	1900	270
Chloride	1500-43000	16625	1500	14000	8000	43000
SOG	2100-10000	[illegible]75	6780	5420	2100	10000
Sulphate	300-7000	3250	300	3000	2700	7000

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Appendix 1: Standards for the discharge of industrial effluents into municipality sewers

Parameter	Unit	Limit (Max)	Parameter	Unit	Limit (max)
pH unit	pH unit	6.5 - 12.0	Iron	mg/l	25
Temperature	^0C	<45	Zinc	mg/l	15
Total solids	mg/l	2000	Cadmium	mg/l	10
Conductivity	uS/cm	300	Chromium	mg/l	10
Suspended solids, SS	mg/l	600	Copper	mg/l	10
Chemical Oxygen Demand (COD)	mg/l	2000	Lead	mg/l	10
			Nickel	mg/l	10
Dissolved sulphate	mg/l	300	Others	----	As specified in the by- laws
Cyanide	mg/l	10			
Soap, Oil and grease	mg/l	10			