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Redesigning waste water treatment process in view of utilising the water: A case study at a citrus juice processing company in Zimbabwe

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Abstract: Disposal of industrial wastewater from a local citrus juice processing company was found to be resulting in negative environmental impacts on the vegetation surrounding the disposal site and the treated wastewater did not meet the minimum purity requirements stated in the Zimbabwe Environmental Management Act (Chapter 20:27). This project was aimed at redesigning the process so that wastewater which meets required legal requirements for quality is discharged and made available for different purposes. Samples of wastewater were collected at the company's effluent processing plant and experiments were conducted to assess its overall quality. The process was redesigned based on the shortcomings found. The redesigned wastewater treatment prototype gave water that was legally fit for disposal, with an average pH of 7.6 and could be used for irrigation purposes.

Keywords: Effluent, Influent, Wastewater, Flow Equalization, Dissolved Air Floatation (DAF), Dissolved Oxygen

1. Introduction

Water reuse is implemented in many parts of the world to cope with increasing water shortage. Currently, water conservation and the use of reclaimed wastewater are being considered as strategic solutions in different parts of the world including arid and semi-arid countries. Wastewater reuse results in minimizing environmental pollution as well as the demand for fresh water [36].

According to Standards for Waste Management (Section 69) of the Zimbabwe Environmental Management Act, no person is allowed to discharge or dispose off any waste that can cause pollution of the environment or make people ill. Every food industry sector is required by environmental agencies to have a system that treats its wastewater before disposal. The wastewater at the company in this study was suspected to be negatively affecting the growth of vegetation in the area. Concomitant surface disposal of solids and fouling of the disposed effluent have led to the death of vegetation around the disposal site.

The company under the present study is domiciled in a semi-arid region with an average annual rainfall of 331mm. Recycling effluent water offers an alternative source of water that could help alleviate water shortages in the drought-prone town.

Citrus is the largest fruit crop in the world with about 60 000 000 MT (1MT=1000kg) grown, slightly exceeding grape production (FAO, 1999). Citrus fruits are consumed as fresh fruit or processed into citrus products and by-products, for example cordial drinks. Approximately one third of the total citrus production is utilized for processing [39].

Citrus juice is commonly marketed in three forms: as a frozen concentrate, which is diluted with water after purchase; as a reconstituted liquid, which has been concentrated and then diluted prior to sale; or as a single strength, non-concentrated beverage called Not From Concentrate (NFC) [39] . In producing these types of beverages, water is used in many areas around the plant [4] . Industrial wastewater is a semi-liquid waste that is discharged from industries. Wastewater generated from food industry and citrus processing is has distinctive characteristics as compared to common wastewater managed by public or private waste water or sewage treatment plants. It is bio-degradable as well as non-toxic in nature, containing high levels of biochemical oxygen demand and other suspended solids [15] .

1.1. Categorization of Wastewater Treatment in Food Processing Industries

Wastewater treatment is the removal of solid materials, inorganic and organic compounds from used water with the subsequent conversion into environmentally acceptable water, or potable water . The treatment of wastewater is categorized into primary, secondary, tertiary and advanced treatment as shown in Figure 1. The type, amount and end use of waste material in the wastewater determines the extent of the treatment and most beverage industries treats to the tertiary stage [15] .

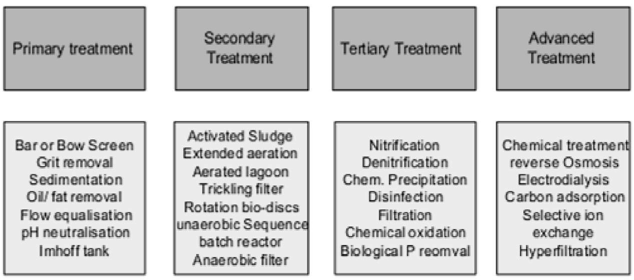

Fig 1. *Water treatment categorization and their technologies (Veenstra, 1996)*

The primary waste from citrus-processing plants is generally liquid or aqueous waste. Regardless of the source, citrus waste streams contain basically four types of contaminants: suspended and settle-able solids (such as juice sac material, pulp and waxes); soluble organics (primary sugars and acids), soluble inorganic (caustic sodas) and volatile organics (d-limonene from peel oils).Various method combinations can be used to treat this type of waste depending on the end use of the wastewater and resources available [20] .

2. Materials and Methods

The researchers collected samples of wastewater in order to determine the suitability of the effluent for disposal. The physico-chemical composition of the effluent water was analysed. The results were compared to those limits required by the Environment Management Act Chapter (20:27) for using wastewater for irrigation. These findings to redesign processes of the effluent plant. The physico-chemical composition of the wastewater that was produced by the redesigned process was similarly analysed. and compared with legal limits. These steps are shown in Figure 2.

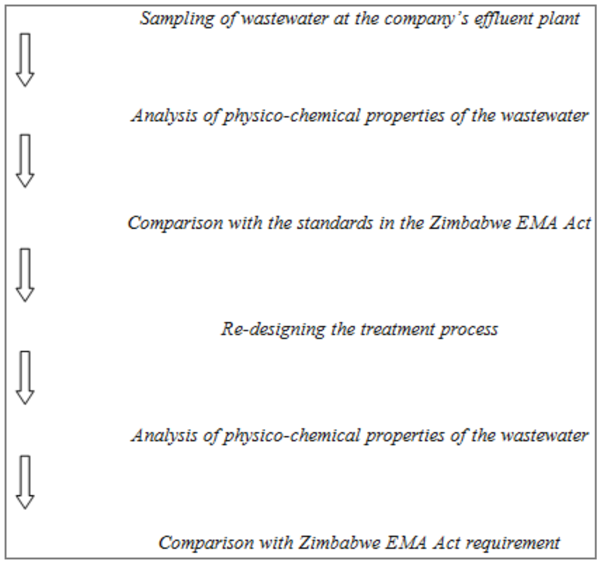

Figure 2. *Flow diagram of the research methodology*

2.1. Data Collection and Sampling Techniques

Wastewater samples were collected in plastic containers previously cleaned by washing in a non-ionic detergent, rinsed with tap water, soaked in 10% HNO_3 for 24 hours and finally rinsed with deionized water prior to usage. During sampling, sample bottles were rinsed with the sampled water three times and then filled to the brim. Samples of wastewater were collected from the company's effluent plant as well as from the redesigned wastewater treatment prototype.

Samples were taken at hourly intervals for 24 hours and mixed to make composite daily samples.

Samples were collected at different stages of treatment and the tests performed on the samples are shown in Table 1.

Table 1. *Tests performed on different wastewater samples*

		Influent	**Company effluent**	**Wastewater from prototype**
Site of sample collection	Number of samples collected daily for 3 months	Test done	Test done	Test done
Before effluent treatment	90	Overall composition of influent		
After screening	90		Suspended solids	Suspended solids
After pH neutralization	90		pH	pH
Aerobic treatment	90		Dissolved oxygen, Oil and grease, BOD,COD and temperature	Dissolved oxygen, Oil and grease, BOD,COD and temperature
Sedimentation tank	90		Dissolved solids	Dissolved solids
Disinfection	90		Total bacteria count and odor	Total bacteria and odor

The parameters most pertinent to these studies included pH, alkalinity, chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), chloride content and fecal coliform content.

Determination of certain parameters required on-site testing of grab samples (e.g., turbidity, pH, and free residual chlorine). Bacteriological examination was carried out on grab samples from the final effluent downstream chlorine contact tanks, collected in sterile plastic bags containing sodium thiosulfate pellets for dechlorination of samples and transferred to the laboratory for immediate analysis.

Determination of temperature and dissolved oxygen were performed on site. For the rest of the tests, samples were preserved with nitric acid at a pH of less than 2, stored in the refrigerator at 4°C prior to further analysis.

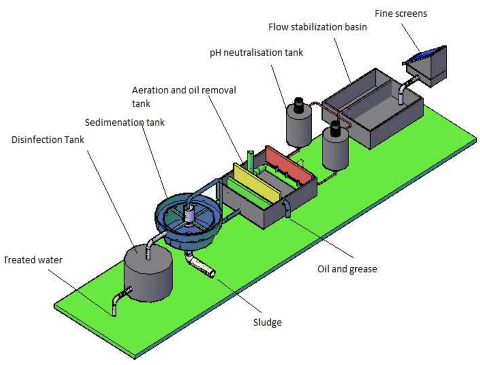

Figure 3. *Re-designed wastewater prototype model*

2.2. Methods and Techniques

A series of experiments on the composition of the wastewater from both the wastewater from the company's effluent plant and the redesigned wastewater treatment process prototype were carried out. The tests performed included the following experiments and they were done according to the Standard methods for the examination of water and wastewater American Public Health Association. The experiments performed were on the determination of pH, suspended solids, dissolved solids, temperature, BOD, COD, oil / grease odour and total bacterial counts.

2.3 Fabricating the Redesigned Wastewater Treatment Prototype

Scaling down of the dimensions and flow rates of the company's effluent plant was done to come up with the re-designed prototype (Figures 3 and 4). All the equipment was designed using galvanized steel. The redesigned prototype employed gravitational flow, rather than pumps to move wastewater between the different stages and valves were used to regulate the flow rate of the wastewater during the treatment.

2.4. Detailed Design

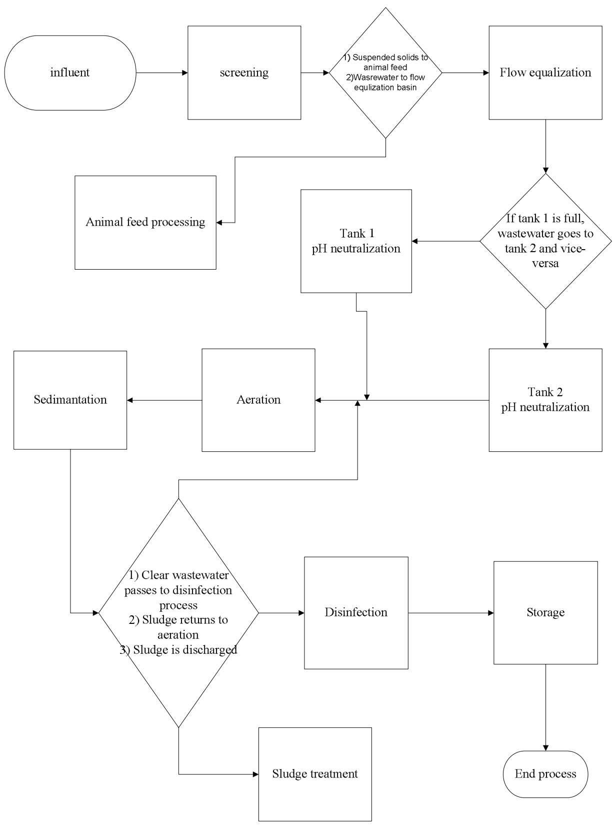

Figure 4. *Process flow diagram illustrating the redesigned effluent plant*

2.5. Design Inputs

- The screen dimensions: a width of 3.8m, length of 1.5m, and 25mm pores size. The slope of the screens is 45 degrees to allow easy movement of waste solids to the collecting zone and the inclined height is 2.7m.
- The basin consists of a two rectangular basins which are constructed from bricks and motor and plaster inside with a corrosion free material. The one meant for mixing wastewater of different strengths has a holding capacity of 1000 liters of water in an hour and had dimensions of a height of 2m, length of 2.5m, width of 2m and a volume of 10m^3. The small basin has a capacity of holding 4000 litters produced during cleaning-in-place and had dimensions of a height of 2m, length of 1m, width of 2m and a volume of 4m^2. A pump slowly adds the alkaline wastewater from the small basin to the mixing basin which has a holding capacity of 0.5m^3 per hour. The flow rate of the wastewater entering the flow stabilization pond is 10m^3 per hour whilst the capacity of the pump removing wastewater from the mixing basin is 12m^3 per hour.
- The tanks each have a radius of 0.52m, height of 1.5m and an area of 10m3 each as. Each tank has a holding capacity of 10000 liters per hour. This gives the wastewater in the each tank a residence time of one hour in which the wastewater's pH should be neutralized. Each tank has a mixer to thoroughly mix the wastewater and the added alkali
- The dimensions of the basin were a height of 1.5m, length of 4m, width of 2m and a volume of 12m^3. A pump with capacity of 10000 liters is used to pump the pH treated wastewater into the aeration basin. An air pump which can be varied and with a maximum capacity of introduces oxygen into the wastewater. An equipment of skimming oil and its dimensions are shown in the diagram above. A return process is included where one quarter of the sludge is pumped back to the receiving pipe of the aeration tank as shown in the diagram.
- The dimensions of the sedimentation tanks were a height of 3m, radius of 0.7m and a volume of 30m^3.
- The dimensions of the disinfection basin were a height of 2m, width of 1m and length of 2.5m

3. Results

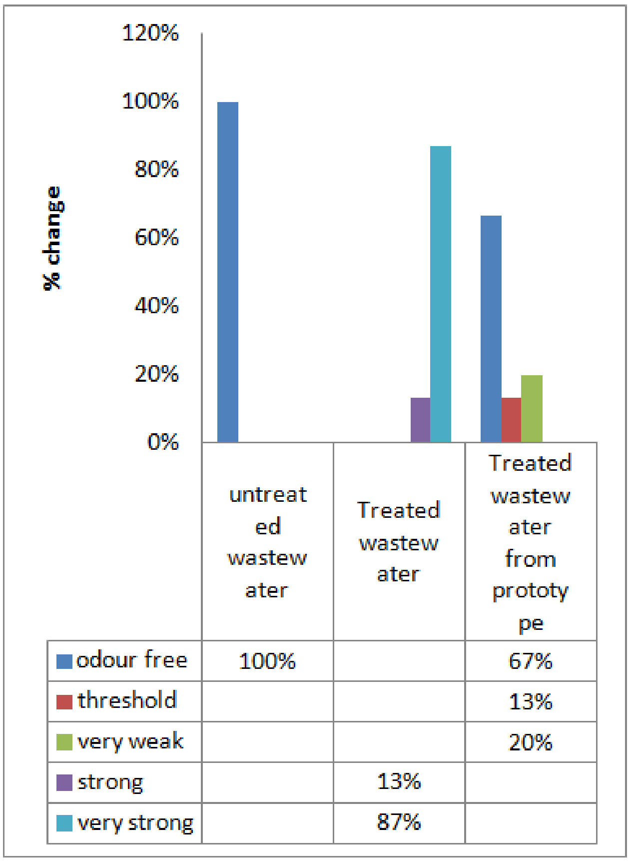

Fig 5.1. *Sensory evaluation of wastewater on odour*

Table 2 summarises the physico-chemical attributes of treated and untreated wastewater.

Table 3. *Physical attributes of untreated wastewater and treated wastewater*

Parameters	**Untreated wastewater**	**Treated wastewater from company**	**Wastewater treated by the prototype**	**Required permissible limits (EMA Act)**
pH	4.3± 0.9	4.9± 0.5	7.4±0.3	6.5-8.5
Temperature	37^{O}C±2	30 ^{O}C±1	26 ^{O}C±1	20-35 ^{O}C
Suspended solids	1700 mg/l±10	40 mg/l±5	25 mg/l±1	100 mg/l
Dissolved solids	848 mg/l±12	420 mg/l±13	134 mg/l±6	200 mg/l
COD	3200mg/l ±11	128mg/l±5	52 mg/l±2	60 mg/l
BOD_5	1440 mg/l±12	280mg/l±8	25 mg/l±1	30 mg/l
Parameters	Untreated wastewater	Treated wastewater from company	Wastewater treated by the prototype	Required permissible limits (EMA Act)
Dissolved oxygen	1ppm±0.02	0.8ppm±0,01	2.5ppm±0.03	<2ppm
Oil and grease	900 mg/l±10	600mg/l±6	10 mg/l±2	

Table 4. *Microbial analysis of untreated wastewater and treated wastewater*

Parameter	Untreated wastewater	Treated wastewater from Company	Wastewater from the prototype	Required permissible limits (EMA Act)
Total Bacteria	20 000±50 counts/100ml	20500±50 mg/l	8000±25 mg/l	10,000 counts/100ml

Table 2.4. *Sensory evaluation results of odor from untreated wastewater and treated wastewater*

Scale	Untreated wastewater	Wastewater treated by Company plant	Wastewater treated by prototype	Permissible limits (EMA Act)
Odour free	15	-	10	No odor
Threshold	-	-	2	-
Very weak	-	-	3	-
Weak	-	-	-	-
Moderate	-	-	-	-
Strong	-	2	-	-
Very strong	-	13	-	-

4. Discussion

The principal objective of wastewater treatment is generally to allow industrial effluents to be disposed of without causing danger to human health or unacceptable damage to the natural environment. Some degree of treatment must normally be provided to raw industrial wastewater before it can be used for agricultural or landscape irrigation. The most appropriate wastewater treatment to be applied before effluent use in agriculture is that which will produce an effluent meeting the recommended microbiological and chemical quality guidelines both at low cost and with minimal operational and maintenance requirements [5] . The results of this study indicate that, in general, the re-designed prototype system is more efficient than the system the company was using for wastewater treatment at the time of the investigations:

a) *Suspended solids*

The company's wastewater treatment plant reduced the suspended solids from 1700mg/l (in the influent) to 45mg/l. The prototype system reduced the suspended solids value to 34mg/l, and the greater efficiency in the latter system may be attributable to the use of finer screens.

b) *pH*

Raw wastewater before treatment had an average pH of 4.3. Citric acid and other acids including malic acid, oxalic and tartaric acids account for the acidic pH. The wastewater produced by the company had a pH of 4.9 after neutralization of acids. The wastewater from the prototype had a pH of 7.4 which was in the permissible legal range for disposal and which is also conducive for the proliferation of aerobic microorganisms. Hence the prototype design, which employs a batch system for acid neutralisation proved to be more efficient than the continuous system that the company makes use of. Additionally, with the new prototype design residence time and flow of wastewater can be monitored and controlled before allowing it to proceed to further processing steps, making this model quite flexible in its functionality.

c) *BOD and COD*

The untreated wastewater had a high BOD and COD of 1440mg/l and 3200mg/l respectively. These two parameters are used to measure pollution levels of wastewater by organic compounds. The organic matter in wastewaters is typically a mixture of proteins and carbohydrates as well as oils and fats (Hiisvirta, 1976). The prototype system exhibited greater efficiency, because after treatment of the water, the BOD and COD values were lower than obtained with the current system the company employs (Table 3). The wastewater treatment system at the company had no aeration stage incorporated but the prototype wastewater had a lower BOD and COD because air was incorporated in the treatment process which allowed waste material to be oxidized by aerobic microorganisms.

d) *Oil and grease*

The influent wastewater has 900 mg/l of oil (Table 3). The oil was removed to a lesser extent in the company's conventional water treatment system (600mg/l oil remaining after treatment) from the effluent wastewater as compared to the prototype (10mg/l oil remaining after treatment). Oil is removed at the aeration stage in the prototype model where the oil floats and is skimmed off. The resultant water from was suitable for discharge into the environment.

e) *Dissolved solids*

The sugars and acids together with small amounts of pigments, minerals, vitamins and proteins are generally referred to as dissolved solids [38] . The influent wastewater had dissolved solids of 848mg/l. The company's wastewater treatment system reduced the dissolved solids to 420mg/l (Table 3). The lack of a flow stabilization basin in the system meant that the wastewater flow rate to the clarifier was not controlled. If high flow rates were experienced, less than ideal settling occurred due to disturbances to the settling process. Moreover, high velocities encourage re-dissolving of the settled matter. In addition, the small dimensions of the sedimentation tank meant that residence time in the tank was too short to enable adequate sedimentation of dissolved solids. Improvements on the prototype design (incorporation of a flow equalization basin and use of coagulants) enabled the suspended solids to be reduced to 134mg/l which is within the legal limits.

4.1. Microbial Evaluation of Untreated Wastewater and Treated Wastewater

Using wastewater of high microbial contamination for irrigation could cause health problems for workers and can impose a hazard to the food industry. In order to reduce the microbial load in this wastewater treatment plant, some additional treatment, such as sand filtering followed by UV disinfection, is recommended . The wastewater from the industry was contaminated and after being treated there was no significant reduction in the microbial load. The microbial load increased from 20 000mg/l to 20500mg/l and this may have been due to further contamination of the wastewater downstream. In the prototype, a disinfection stage was incorporated resulting in the reduction of the microbial load to 800mg/l which is within the limits required by the EMA Act. The disinfection proves useful for to reducing the microbial load of the wastewater so that it can be safely discharged.

4.2. Sensory Evaluation of Untreated Wastewater and Treated Wastewater

Anaerobic respiration of microorganisms produces undesired odorous compounds. 87% of the panelists agreed that the wastewater from the effluent had a strong odour and 13% of them agreed that it had a strong odour produced by compounds like sulphides. The wastewater from the prototype had a barely perceptible odour because the aeration stage was included in the process. 67% of the panelist agreed that it was odor free, 13% agreed that it was the threshold odor and 20% agreed that it was a weak odor. Aerobic respiration prevents odorous compounds from being produced from the wastewater [11] .This shows that aerobic treatment is a viable solution to removing the strong odours.

5. Conclusion

In many parts of the world, treated wastewater has been successfully used for the irrigation, and many researchers have recognized its benefits [26] ; Levine and Asano, 2004). The effluent plant at the company investigated did not produce wastewater of required permissible limits, so the process required to be redesigned. The wastewater that was produced by the redesigned system met the requirements stated by the EMA Act: Chapter (20:27).

Note

The company under investigation could not be named as per agreement between the company executives and the researchers.

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