Performance and Loading of Domestic Wastewater Treatment Plants Receiving Aquaculture Processing Effluent.

GOVERE [*,1]SIMBARASHE, MAHLATINI[1] PRECIOUS, NDABANINGI[2] ANGELINE

[*, 1] Lecturer/ Department of Environmental Sciences and Technology, Chinhoyi University of Technology, Chinhoyi, Zimbabwe. Simgovere2000@yahoo.com
[2]Research Officer/ Batsirai Group, Chinhoyi, Zimbabwe

***Abstract-* This study dealt with the loading and performance of a domestic wastewater treatment plant when receiving combined influent from an aquaculture processing factory and an urban settlement in Kariba town, Zimbabwe. The methodological framework was a case study approach involving a local aquaculture factory and two treatment plants. In the study effluent from Nyamhunga treatment plant, which receives both domestic and aquaculture effluent, acted as the treatment. Effluent from a similar-sized plant, Mahombekombe treatment plant, which only receives domestic wastewater acted as the control. Influent and effluent samples from both plants were collected over a 6 months period. Effluent samples were also taken from the aquaculture factory. The samples were analyzed for Chloride, Total Nitrogen, Biological Oxygen Demand and Fats, Oils and Grease using standard laboratory techniques. Research findings show that Mahombekombe treatment plant was more efficient than Nyamhunga treatment plant. Nyamhunga treatment plant effluent registered significantly higher concentrations for all tested parameters compared to Mahombekombe treatment plant. Effluent from the aquaculture factory significantly increased the wastewater load received by Nyamhunga treatment plant, in both volume and composition. The findings of the study suggests that coupling treatment plants to aquaculture processing facilities might not be a good practise since the former increases the load and concentrations of wastewater significantly affecting performance.**

Key Words: aquaculture processing, domestic wastewater treatment plants

I. INTRODUCTION

Aquaculture, the farming of aquatic organisms such as fish, molluscs, crustaceans and plants, is the fastest growing food production sector in the world [1]. Aquaculture has great potential for food production and the alleviation of poverty for people living in coastal areas, many of whom are among the poorest in the world. Associated with aquaculture is fish processing which is defined as the processing of either fish or shellfish into a variety of fish products, and the subsequent canning or packaging of these products [2]. The processes, which are carried out at the local or industrial level, include smoking, chilling and freezing, canning, filleting and production of other value-added products [3]. The end products from fish processing may be fresh, frozen or marinated fillets, canned fish, fish meal, fish oil or fish protein products [4].

A. Characteristics of aquaculture processing effluent

Fish processing activities are known to generate large quantities of organic waste and by-products from inedible fish parts and endoskeleton shell parts from the crustacean peeling process [2, 5]. Wastewaters from fish processing plants are usually high in proteinaceous compounds and oils. Fish processing wastewater has a high organic content and subsequently a high Biochemical Oxygen Demand (BOD) because of the presence of blood, tissue, and dissolved protein [6]. It also typically has a high content of nitrogen (especially if blood is present) and phosphorus. Major types of wastes found in fish processing wastewaters are blood, offal products, viscera, fins, fish heads, shells, skins and meat "fines." These wastes contribute significantly to the suspended solids concentration of the waste stream. Detergents and disinfectants may also be present in the wastewater stream after application during facility cleaning activities. The disinfectants commonly used include chlorine compounds, hydrogen peroxide, and formaldehyde [5].

Carawan *et al.* [6] reported on an EPA survey with BOD, COD, TSS and fats, oil and grease (FOG) parameters. Bottom-fish processing waste streams were found to have a BOD_5 of 200-1000 mg/l, COD of 400-2000 mg/l, TSS of 100-800 mg/l and FOG of 40-300 mg/l. Fish meal plants were reported to have a BOD_5 of 100-24,000 mg/l, COD of 150-42,000 mg/l, TSS of 70-20,000 mg/l, and FOG of 20-5,000 mg/l. The higher numbers were representative of bailwater only. Tuna plants were reported to have a BOD_5 of 700 mg/l, COD of 1600 mg/l, TSS of 500 mg/l and FOG of 250 mg/l. Seafood processing wastewater was noted to sometimes contain high concentrations of chlorides from processing water and brine solutions, and organic nitrogen (0-300 mg/1) from processing water.

In an EPA report[7] the authors reported on a study that examined the waste from a tuna canning and by-product rendering plant in detail for a five-day period. The average waste flow was 30, 9 m^3/t of fish with a $BOD_5$500-1,550 mg/l. The average daily COD ranged from 1,300-3.250 mg/l and the total solids averaged 17,900 mg/l of which 40 percent was organic.

Civit *et al*.[8] reported on a study that characterized wastewater effluent from fish processing in Argentina. The COD of the waste stream was 93, 000mg/l with the lipids concentration at 0.12mg/l. Fish processing industries require large amounts of water and are frequently inefficient users of water [9]. The water is used primarily for washing and cleaning purposes, but also as media for storage and refrigeration of fish products before and during processing. Tuna processing plants were reported to have wastewater discharge as high as 16, 363 m^3/day whilst fish meal plants ranged from 45.45- 418.18 m^3/day [10].

B. Treatment of aquaculture processing effluent

Fish processing wastewater is typically discharged into local water bodies (freshwater or marine) or into municipal sewers [2, 11].Fish-processing. industries have been known to have impacts on the environment and wastewater treatment process [12, 13, 14]. Aquaculture processing effluent may contain a variety of constituents that can cause negative impacts on domestic wastewater treatment processes, when disposed without prior treatment [15.] Overloading caused by the high effluent volumes often results in reduced retention times of the wastewater. This result is poorly treated wastewater. Excess quantity of nutrients (nitrogen and phosphorus) may cause proliferation of algae and affect biological processes in domestic wastewater treatment plants.In Zimbabwe, like in most African countries, the norm is to connect aquaculture facilities to domestic wastewater treatment plants (DWTP) [2, 11]. Hence there is the risk that poorly treated waste can potentially find its way into water bodies.

The study sought to determine the impact of aquaculture processing effluent on the performance and loading of Nyamhunga and Mahombekombe DWTPs. This involved chemical analysis of effluent for Total Nitrogen (TN), Biological Oxygen Demand (BOD), chlorides and fats, oils and grease (FOG).

II. MATERIALS AND METHODS

A. Study site

The study was carried out in Kariba Town (lat 16°30'-17°00'S long 20°00'-29°40'E) which is located in the Mashonaland West province of Zimbabwe, on the North Eastern border with Zambia (see Figure.1 above).

Fig 1: Location of Kariba Town in Zimbabwe

The population is approximately 40 000 with 80% concentrated in the Nyamhunga and Mahombekombe townships. Over the past two decades, there has been an increase in aquaculture activities in Kariba (especially under crocodile and fish farming and processing), of which the aquaculture factory under study is one of the largest fish farming and processing entities. The factory produces both fresh chilled and frozen fillets together with whole-gutted fish for export to Europe and the regional market, with a maximum daily production of 12 tonnes of fish. The aquaculture factory is located near Nyamhunga Township and it discharges untreated aquaculture effluent into the Nyamhunga DWTP. Constructed in the 1960's, the wastewater treatment systems at Nyamhunga and Mahombekombe consists of waste stabilisation ponds, each with a carrying capacity of about 650m³/ day.

Fig 2: Schematic diagram of the study area showing sampling points

TABLE 1: DESCRIPTION OF SAMPLING POINTS

Site	Description
1	Effluent from the factory only.
2	Effluent from Nyamhunga domestic sewage pipe only.
3	Combined effluent from Nyamhunga domestic and factory effluent before treatment.
4	Effluent from Mahombekombe wastewater before treatment.
5	Effluent from Nyamhunga domestic wastewater treatment plant after treatment.
6	Effluent from Mahombekombe wastewater after treatment.

B. Chemical Tests

Effluent samples were collected from 6 sampling points as indicated in figure 2 and Table 1 above. The concentrations of TN, BOD, Chlorides and FOG were measured using standard laboratory techniques highlighted below.

TABLE 2: CHEMICAL TESTS PROCEDURES

Parameter	Test
FOG	Direct Hexane Extraction Method
Chlorides	Mohr's Method
BOD_5	Winkler method
Total Nitrogen	Kjedjal method

A. Quantifying Effluent volume

A flow meter was submerged into the effluent conduits to measure the quantity of effluent water discharged per day from the aquaculture factory (site 1), Nyamhunga sewage flow (site 2), total flow into Nyamhunga domestic wastewater treatment ponds (site 3) and amount discharged into Mahombekombe wastewater treatment ponds (site 4). This was done 2 times a day every month for 3 months.

B. Treatment Plant Efficiency

Efficiencies of treatment ponds were calculated from the results of the physical and bio-chemical parameters of the domestic treatment ponds before and after treatment as follows:

$$- \qquad (1)$$

Where;

eff x is the treatment plant efficiency for the reduction in chemical parameter x.

C is the concentration of chemical parameter in influent (before treatment).

C is the concentration of chemical parameter in effluent (after treatment).

Overall Treatment Plant Efficiency was taken as the average of the efficiencies for all parameters.

C. *Fish Processing Effluent Guidelines*

According to the Environmental Management Agency (EMA) Operational Guidelines for the control of water pollution in Zimbabwe [16], ponds which discharge directly or indirectly into a domestic sewer are governed by the normal band limits (see Table 3 below). International regulations are rare and most international organisations recommend the use of local standards. This complicates comparison between different studies. The IFC Environmental, Health and Safety Guidelines are among the few comprehensive international regulations in existence[5]. The IFC Guidelines for Fish Processing include information relevant to fish processing facilities, including the post-harvest processing of fish, crustaceans, gastropods, cephalopods, and bivalves ("fish products"), originating from sea or freshwater catch or from farming operations in fresh or salt water .

TABLE 3: IFC AND EMA EFFLUENT GUIDELINE VALUE

Constituent	IFC Guideline Value	EMA Guideline
pH	6 – 9	6-9
BOD_5 mg/l	50	<30
COD mg/l	250	-
Total nitrogen mg/l	10	<10
Oil and grease mg/l	10	<2.5
Chlorine	-	<250

III. RESULTS

A. *Effluent Volumes*

The aquaculture factory discharges significant volumes (568± 20m³/d), into the domestic treatment plant while Nyamhunga and Mahombekombe sewers discharges were almost similar, discharging 345± 14m³/d and 350±15 m³/d respectively (see table 4 below).

TABLE 4: MEAN MEASURED EFFLUENT VOLUMES

Sampling site	Aquaculture Factory effluent	Nyamhunga Township effluent	Combined Nyamhunga Factory ef.	Mahombekombe Township effluent	*Carrying capacity.*
Flow (m³/d	568± 20	345± 14	898± 33	350±15	*650*

Aquaculture processing facilities use high volumes of water. Kuang *et al* found water use volumes of between 400-765m³/d for 31 aquacultures along Lake Victoria[17]. Large volumes is due to processes involved (filleting, fluming, cleaning, thawing).Total discharge into Nyamhunga DWTP was significantly higher (890m³/d) than that of Mahombekombe (350m³/d) due to the discharge of the aquaculture factory. The high volumes of influent into Nyamhunga DWTP probably reduce the retention time of the wastewater within the DWTP thus reducing its performance [18].

B. *Fats oil and grease (FOG)*

Aquaculture factory effluent (site 1) had high FOG values (45 ±7mg/l) compared to effluent from both DWTP (sites 2 and 4) as shown in table 5 below. The high values of FOG in the factory effluent are due to high FOG from bleeding of fish and evisceration [19, 20].

TABLE 5: RESULTS SHOWING MEAN VALUES OF TESTED PARAMETERS

Parameter	FOG	Chloride	TN	BOD_5
Site1	45 ±7	519± 87	16.1± 3	119±21
Site 2	5.2±2.2	98± 15	6.3±3.1	79±10
Site 3	47±5	562± 90	23.34± 7	145.6± 7
Site 4	5.5±4	99±34	5.4± 8	84±11
Site 5	40.45	456± 92	22.5±6.3	64±12
Site6	2.1	55± 5	2.1± 0.2	69.5± 13

The observed values for site 1 are above the stipulated IFC effluent guidelines (10mg/l) for FOG in any fish processing industries. The highest FOG values were for site 3 (Nyamhunga and aquaculture combined;

47±5mg/l). Statistical analysis showed that there was no statistical difference ($p < 0.05$) in FOG levels between the factory effluent and the combined factory and Nyamhunga effluent (see Fig 3). From the results, it can be deduced that the aquaculture factory is contributing most of the FOG into the Nyamhunga DWTP. Although there is a statistical difference ($p < 0.05$) between site 3 (combined factory and Nyamhunga effluent) and site 5 (treated effluent from Nyamhunga DWTP) the fact that the latter still contains FOG values in excess of 10mg/l (IFC effluent guidelines) means the performance of Nyamhunga DWTP is compromised by the high FOG contained in the factory effluent. The high FOG content of fish processing wastewater may lead to the formation of a thick layer of fat that covers the surface of the aerobic pond used for wastewater treatment. This reduces the pond aeration and consequently lowers its efficiency [21]. The fats may also cling to wastewater ducts and reduce their capacity in the long term.

Fig 3. Variation of sampled FOG values

Fig 4. Variation of sampled BOD values

Fig 5. Variation of sampled nitrogen values.

Fig 6. Variation of sampled chloride values.

* Graphs with the same letters are not significantly different (ANOVA $p < 0.05$).

A. Chloride Concentration

The highest concentration was recorded from site 3 (combined effluent for Nyamhunga and the Aquaculture factory; 562± 90 mg/l) whilst the lowest values were from site 6 (treated effluent from Mahombekombe; 55± 5 mg/l). Effluent from Nyamhunga and Mahombekombe had no significant difference in chloride levels (sites 2 and 4). This is expected as both sites consist of the same effluent type (domestic wastewater) from townships of almost equal populations. The aquaculture factory (site 1) had significantly higher values (519± 87mg/l) compared to the township effluents (site 2 and site 4) 98± 15mg/l and 99± 11mg/l respectively. As can be observed from Figure 6 statistical analysis showed a significant variation in chloride concentration ($p < 0.05$) between site 1 (factory effluent; 519 mg/l), site 3 (combined factory and Nyamhunga effluent; 562 ± 90 mg/l) and site 5 (Nyamhunga DWTP effluent; 456± 92mg/l). Firstly this indicates that both factory effluent and Nyamhunga effluent are responsible for the high salt levels in Nyamhunga DWTP, although the factory contributes approximately 92% of the salts. Secondly it reveals that Nyamhunga DWTP has some significant reducing impact on the salt levels it is receiving. However even after its modest impact the salt level is still too high (456± 92mg/l), definitely above EMA regulations (250mg/l) compared to the levels for treated effluent from Mahombekombe after treatment (55± 5mg/l).

B. Total Nitrogen

The results show that the Aquaculture factory effluent (site 1) contained total nitrogen levels of 16.1± 3mg/l which are above the IFC effluent guidelines of 10mg/l (see Fig. 5). The highest value (23.34± 7mg/l) was from combined factory and Nyamhunga effluent (site 3) and the lowest value (2.1± 0.2mg/l) from Mahombekombe effluent (site 6) after treatment. There was a significant difference ($p < 0.05$) between the factory effluent (site 1) and Nyamhunga and Mahombekombe township effluent (sites 2 and 4). This shows aquaculture effluent contains more nitrogen than domestic effluent. Aquaculture effluent contains high concentration of nitrogen from bleeding, evisceration, and filleting and can also be introduced with processing and cleaning agents [22]. Mahombekombe DWTP was able to reduce the total nitrogen load to within the EMA standards of 10mg/l whilst Nyamhunga failed to do so. This portrays the negative effect of the aquaculture factory on the ability of Nyamhunga DWTP to perform to local standards. The presence of detergents in the aquaculture effluent most likely inhibited microbial action on the nutrients resulting in poor wastewater treatment as shown in other studies [23].

C. BOD_5 level

The results showed variation in BOD_5 levels between sampling sites. The highest BOD_5 level (145.6± 7mg/l) was seen from combined effluent of Nyamhunga Township and the factory (site 3) and the lowest levels (69.5± 13mg/l) from treated effluent from Mahombekombe DWTP (site 6). The factory effluent failed to meet the 50mg/l BOD_5 standard recommended by the IFC. This could be due to the high organic load, fish oils & detergents from fish processing effluent which require a lot of oxygen to degrade them by micro-organisms. Revenga reported high BOD values from fish processing in the Nile Perch[24]. High BOD values for trout-processing were reported by Hwang and Hansen [25]. There were significant differences between the factory effluent (site 1) and the untreated effluent from the townships (site 2 and 4). This points to the fact that fish processing effluent generally has a higher organic load than domestic wastewater and therefore demands a lot of oxygen to stabilize. The highest BOD_5 concentration of 145.6± 7 mg/l at site 3 reveals the additive effect of mixing domestic wastewater and fish processing effluent. This highlights the fact that the presence of aquaculture effluent in domestic sewers can substantially alter the nature of the wastewater resulting in poor performance by DWTP [26].After treatment the effluent from Nyamhunga DWTP still contains high BOD above the EMA standard of 30 mg/l.

D. Treatment plant efficiencies

Mahombekombe DWTP was generally more efficient than Nyamhunga DWTP in waste treatment. It had an average efficiency of 61% for all parameters compared to Nyamhunga which had an average efficiency of 31%. This is likely due to differences in composition and volume of effluent discharged into the two treatment plants caused by aquaculture factory. The results above have shown that Nyamhunga DWTP receives a higher nutrient load and effluent volume compared to Mahombekombe DWTP due to discharges from the aquaculture factory. High chlorides, FOG & nutrients are known to impede microbial action on effluent resulting in poor wastewater treatment. Large volumes of effluent cause overloading resulting in reduced retention time of the wastewater thus reducing the efficiency of the wastewater [23, 27].

IV. CONCLUSIONS

The results of this study have shown that the practice of directly coupling aquaculture processing plants to DWTP might compromise the performance of DWTP resulting in potential negative environmental impacts. This was illustrated by the fact that Mahombekombe DWTP is more efficient than Nyamhunga DWTP. Effluent discharged by the aquaculture processing factory directly into Nyamhunga DWTP was of high volume, poor quality and was below the standards recommended by the IFC and the local EMA. This causes Nyamhunga DWTP to process wastewater of high concentration and volume. The factory should initiate a comprehensive Waste Management Plan and Water Demand Management Plan that will help reduce the volume and concentration of the waste generated by the plant. This plan could explore options such as collection of fish by-products and their disposal by decomposition (manure for sale). The three most common methods for utilization of aquatic waste are the manufacture of fish meal/oil, the production of silage or the use of waste in the manufacture of organic fertilizer [11]. This has been successfully done in Norway. Other options would be reduction of water use by reuse and recycling of water. Alternatively a fully functional wastewater treatment plant has to be constructed at the aquaculture factory. Given the characteristics of the waste generated by the factory construction of a simple pre-treatment facility to treat the waste would be inefficient. The factory is producing waste almost equivalent to the combined Nyamhunga and Mahombekombe townships. These two communities compose 80% of Kariba Town. This justifies a mandatory stand alone treatment plant for the factory.

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