

Developing a Cleaner Production System for Citrus Processing: Case study of a developing country

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ABSTRACT

Researches carried to evaluate the effectiveness of stabilization pond systems at MCE in the treatment of citrus processing and sewerage treatment concluded that these systems are not effective in treating citrus and sewerage processing effluents. This was evidenced by the abnormally high levels of COD, Nitrogen and total nitrogen and phosphorous of the pond water which were in some ponds more than five times ZINWA limits owing to poor performance of waste stabilization ponds as they are affected by weather. Pond effluent is discharged into local river that supplies the Mazowe area with domestic water. This research unearthed sources of pollution within the plant and outside the plant and explored cleaner production opportunities for safe disposal of waste. Waste segregation by source and type was done. Most of the waste came from the plant unit operations due spillage, leaking, release of excess inputs into waste streams and failure to fully extract as much useful by products from waste as possible. Some CP options required minor plant modifications involving re-routing and some required the production of alternative salable products from waste by expanding the production chain.

Key words: MCE, ZINWA, waste stabilization ponds, cleaner production

1. INTRODUCTION

Mazowe Citrus Estates is Zimbabwe's largest manufacturer of fruit juice products that produces concentrates, purees and juices mainly from citrus fruits (oranges and lemons), granadilla, apples and guavas. The plant processes over 40 000t/yr of citrus fruit. The organization also houses a laboratory where all tests and product development are done. Effluent from the processing plant and the laboratory flows into the WSP which discharges into the river system that supplies the Mazowe area with domestic water.

Citrus fruits are principally consumed by humans as fresh fruit or processed juice, either fresh chilled or concentrated. After juice is extracted from the fruit, there remains a residue comprised of peel (flavedo and albedo), pulp (juice sac residue), rag (membranes and cores) and seeds. The main citrus by-products from citrus processing are fresh citrus pulp which is the whole residue after extraction of juice, representing between 492 and 692 g/kg of fresh citrus fruit with 600–650 g dry matter (DM)/kg peel, 300–350 g/kg pulp and 0–100 g/kg seeds [6]. Fresh citrus pulp has a titratable acidity of 20 mmol/100 g (db), and a pH of 4.16. [7].

The composition of citrus fruit is affected by factors such as growing conditions, maturity, rootstock, variety and climate [4]. Citrus fruits contain N (1–2 g/kg on a wet basis), lipids (oleic, linoleic, linolenic, palmitic, stearic acids, glycerol, and aphytosterol), sugars (glucose, fructose, and sucrose), acids (primarily citric and malic, but also tartaric, benzoic, oxalic, and succinic), insoluble carbohydrates (cellulose, pectin), enzymes (pectinesterase, phosphatase, peroxidase), flavonoids (hesperidin, naringin), bitter principles (limonin, isolimonin), peel oil (*d*-limonene), volatile constituents (alcohols, aldehydes, ketones, esters, hydrocarbons, acids), pigments (carotenes, xanthophylls), vitamins (ascorbic acid, Vitamin B complex, carotenoids), and minerals (primarily calcium and potassium). These components, either individually or in various combinations cause high COD, BOD, electrical conductivity, total N and P or lower the pH of effluent water.

2. JUSTIFICATION

A research had been carried out by P Taru, N. Zhanda, A.T. Kuvarega and I Sango, (1999) to evaluate the effectiveness of waste stabilization pond (WSP) systems at MCE in the treatment of citrus processing and sewerage treatment as an end of pipe technology applied to wastes at the estate. The study concluded that the waste stabilization pond systems at MCE are not effective in treating citrus and sewerage effluents. This was evidenced by the abnormally high levels of COD, Nitrogen and total nitrogen and phosphorous of the pond water which were in some ponds more than five times ZINWA limits outlined in the Operational Guidelines for the Control of Water Pollution in Zimbabwe, (2000). pH was on average acidic and to a greater extent inhibited other biological treatment mechanisms such as removal of nutrients, [2]. Acidic pH mobilises heavy metals (Chapman, 1996) in water and soils resulting in the leaching of these substances into surface water and groundwater sources. Orange peels are spread over a 1ha causing extensive vegetation degradation and alteration of soil micro-biology.

3. PLANT DESCRIPTION

The effluent system is as shown in fig 1 below. Effluent from the factory and laboratory is discharged into the factory effluent canal which is then screened along the drainage system. This flows through the open drainage that discharges into the WSPs. Sewage waste from the village also flows through the same open drainage canal and discharges into the WSPs.

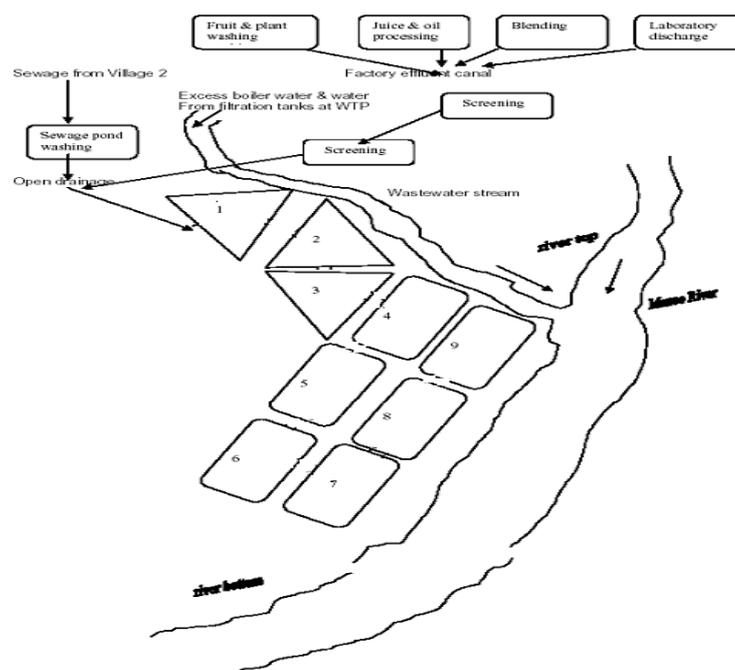


Figure 1: Effluent flow from plant to waste stabilization ponds

Source: P. Taru, et.al

This research was carried out to investigate and quantify the sources of waste that is causing environmental degradation and developing solutions using cleaner production technology. Cleaner Production is the continuous application of an integrated preventive environmental strategy applied to processes, products, and services to increase overall efficiency and reduce risks to humans and the environment.

The Cleaner Production activities promote strategies, policies and practices to prevent pollution from processes, products and services. This is a concept of green manufacturing that emphasises pollution prevention through use of less or non-hazardous materials, waste reduction, recycling and process improvement.

Development and adoption of a CP technology for MCE helps the organization in getting the certification of the International Standards Organisation (ISO) 14000 series certification in a country where only 3 companies had established ISO 14001 certified environmental management systems

by April 2000 from a pull of 80 Zimbabwean companies .

4. METHODOLOGY

Effluent segregation was done to determine the source and type of effluent from the plant and outside the plant. Measurements of volumes were taken directly from installed gauges and meters. Effluent quality parameters, e.g pH, BOD and COD were taken from daily recordings of laboratory tests of effluent. Qualitative information was sourced from plant operators and management.

5. RESEARCH FINDINGS

Sources of waste were identified and quantified as shown in Figure 2 below.

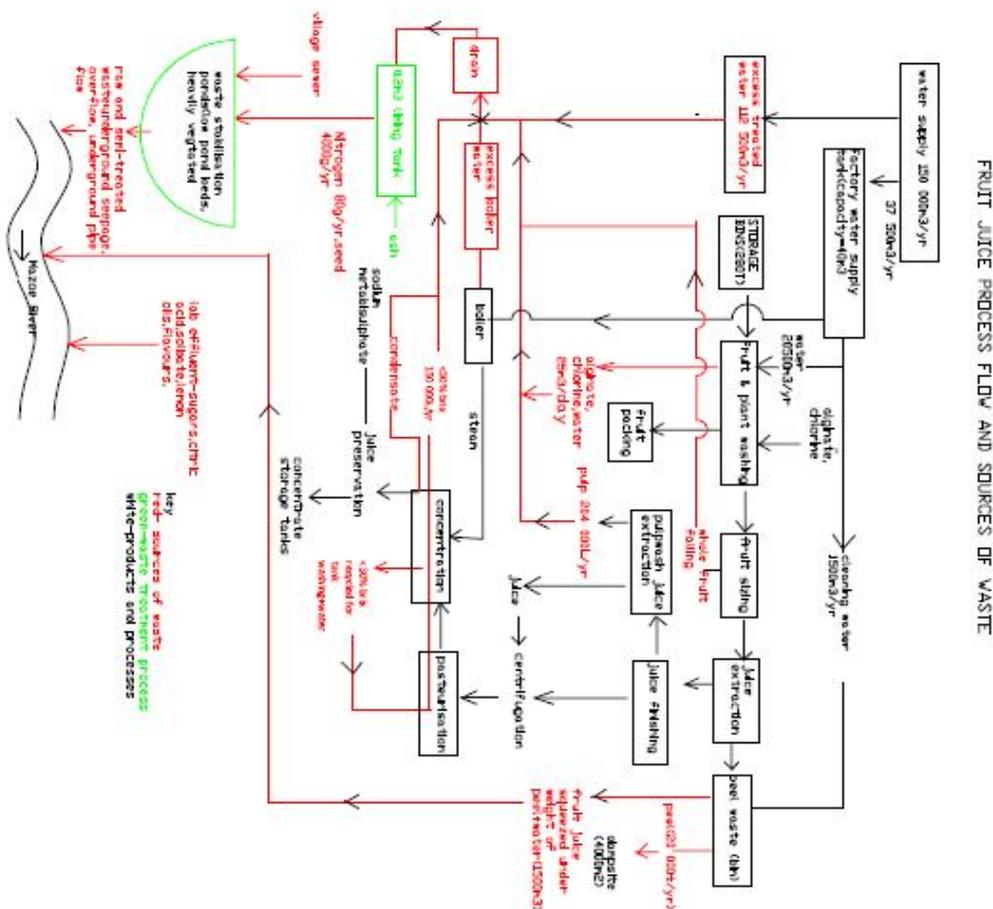


Fig 2. Process flow chart and sources of waste

5.1 Water

5.1.1 Water supply

The factory has a water treatment plant that produces 150 000m³ /yr , (500m³ /day) of water. The factory uses 37 500m³/yr for fruit washing, steam production, laboratory use and cleaning. The tank supplying the plant has a capacity of 40m³ which is an equivalent of 12 000m³/yr. Thus water is continuously pumped from the treatment plant to avoid the exhaustion of water in supply tank whilst the plant is still operating leading to overflowing of 75% of the treated water which is an equivalent of 112 500m³/yr. This water is discharged to the sewer system and goes to the WSPs causing unnecessary water loading. Although this has a dilution effect on the factory waste, the water overloads the ponds causing overflow of semi-treated and untreated waste from ponds into the river. Pond processes are also disturbed because of fresh water agitation.

5.1.2 Leaking valves

The factory has two permanently malfunctioning main valves that stay open continuously releasing water for as long as the plant is operating. These valves supply the plant with water for processing operations and cleaning the floor. This water is discharged effluent.

5.1.3 Boiler Water

Excess boiler water at 100°C and condensed water from evaporator is also discharged as effluent.

5.1.4 Condensate water

Condensate from the evaporator is discharged as effluent in the drains.

5.1.5 Cleaning Water

Peel bin emptying involves the use of over 5m³/day of water used to washout peel through the outlet. The wastewater from the bin area and fruit washers contains about 2 500mg/l of chemical oxygen demand which is relatively a low value compared to other streams of the plant. pH is generally 4. The effluent drains into the conveyance system that discharges into Mazoe River.

5.2 Solid waste

The grading/sorting section has low guards that allow the spilling of whole fruits onto the floor. This and the fruit peel falling from the extractor are washed and drained as part of the effluent. These solid substances block the screens along drainage channel. To avoid blockage of the system, screens have been removed so that solid waste passes easily to the WSPs. The discharge of solid peel waste also leads to high BOD and COD since peel contains limonene

Existing screens along the effluent conveyance are damaged and have holes too large to screen away orange peel or whole fruit. The screen at the peel waste bin is made of iron bars separated at 50mm thus allowing all orange peels with 50mm longest axis and any size of peel falling by its edge. This lets large pieces of peel flow into the effluent conveyance system leading to high acidity, COD and BOD.

Over 20 000t/yr of orange peel waste is produced and spread in a 150mm thick layer over 4000m² waste dump area. This dumpsite is divided into two sections, each with an area of approximately 2 000 m². The second section was opened up when the first section was filled up with peel, vegetation growth retarded and destroyed in some sections. The organization was forced to abandon this area to allow for regeneration, and hence opened up a new area as a dumpsite. With the current production levels, at less than 40%, this new dumpsite area is already filling up leading to opening up of another dumpsite if no alternative use of orange peel is found. At full production, an estimate 10 000 m² area is required for dumping waste. Approximately 2% of this waste is collected by farmers from the dumpsite to feed their cattle.

5.3 Liquid waste

5.3.1 Pulp Waste

Pulp which is centrifuged from the juice extract by the SA 60 centrifuge is discharged as waste. 630L/8hrs of pulp are discharged as factory effluent. The pulp is discharged into the floor drain then to the WTP. Pulp that leaks onto the floor is washed into the drains using horse water. This is also the reason why water tapes are not repaired to close water supply since water is frequently needed to clean such discharges. Citrus juice centrifugation pulp is the semi-solid product obtained from the industrial centrifugation of juices, to obtain a clear juice. This waste causes many economic and environmental problems because of its fermentability

5.3.2 Brix Waste

Evaporator and pasteurizer tank washing is done using 5% juice brix which is discharged to the effluent waterway. During this process, the evaporator section will be set to concentrate juice to the required sugar concentration, (brix) which is usually 30% or more, (the maximum is 65%). The operating procedures are that until the juice of the right brix is obtained at the pipe discharging into the storage tank is obtained, all the unwanted juice is discharged as effluent. In the process cleaning of the tanks will be done. Meter readings show that in this process more than 500L/day of low Brix juice is discharged as effluent contributing heavily to BOD in the WSPs.

5.4 Drainage system Design

Waste water from peel bin and liquid waste from the laboratory drain to the directly to the river without passing through the WSPs for treatment.

5.5 Waste Treatment Plant (WTP)

The WTP consists of liming tank, 9 WSPs and flood pond. Poor performance of these to the discharge environmentally degrading effluent.

5.5.1 Effluent Liming.

The organization uses Calcium Oxide or coal ash to raise the pH of the acidic effluent. The latter is predominantly used. Ash is just spread in tank 1x1x0.2m tank which is along the effluent conveyance system before WSP discharge point. This method of application is inefficient as not all the acidic effluent will find the ash at its greatest strength. Some of the ash is also washed away with flowing effluent. The strength of ash is also unknown resulting in unjustified low volume ash applications in the 0.8m³ liming tank.

Such practices mean that micro-environments are created, i.e. localized alkaline and acidic regions within the same pond, hence uniform pond biological processes cannot be achieved.

5.5.2 Waste Stabilisation Ponds (WSPs)

9 WSPs form part of the waste treatment facilities at the plant. WSP were not desludged since the 1970s. 8 of the 9 ponds are clogged with vegetation. There is subsequently no light penetration to the lower depths of the ponds and air movement is greatly inhibited. Thus bacterial oxidation of organic matter which leads to the production of ammonia, carbon dioxide, sulfates, water and other end products is curtailed if not reduced. Algal activity whose rate is increased by daylight is also reduced leading to low production of oxygen. Oxygen supply to the bacteria is consequently minimized. Thus the pond processes are not feasible at MCE since there is an ecological imbalance. This is caused by the absence of a maintenance management system for the waste treatment plant. Ponds overflow in the rainy season directly into the river. This is because the volume of the ponds are reduced due to sludge bedding which continuously accumulates without desludging. This leads to the release of partially treated waste into the river.

Effluent is discharged into Mazoe River through both underground pipe conveyance and ground seepage. The underground pipe is connected at pond number 8 although it does not have the most favorable chemical and biological properties for disposal. Effluent in pond 9 would have achieved the greatest residence time undergoing biological and chemical conversion and would be the most suitable assuming all processes are completed.

5.5.3 Flood Pond Capacity

The flood pond has a current capacity of 1600m³. This volume does not capacitate the volume of effluent that will be released when there is maintenance work on WSPs. The flood pond can be filled up with factory effluent in 3 days since 500m³/day (37 500m³/yr) effluent is released. This has affected the maintenance works on WSPs since they have to be desludged without loading effluent.

Operator of the pasteurizer section is alerted by overflowing of juice extract from the pasteurizer tank to signal the operator of the extraction section to switch off the extractor power supply. Pasteuriser tank usually fills to overflowing because evaporator section is not operating, so the pasturiser cannot discharge juice extract to the evaporator but contains it until the latter starts operating. There is poor timing of the 4 operations, i.e. extraction, pasteurization, evaporation and emptying the peel bin. Therefore there is need to optimize the 4 processes

The following table summarizes the quality of effluent discharges by the processing plant.

Table 1: Effluent discharge quality

Quality Parameter	ZINWA Limits	MCE Effluent Quality
pH	7	6
EC	1 000uS/m	1000-1300 uS/m(April-Nov) ≤1 000uS/m(Dec-March)
BOD	10mg/L	10-15mg/L
COD	60mg/L	204-1 100mg/L
Total N	10mg/L	≥25mg/L
Total P	0.5mg/L	≥9.8

Condensed water from the evaporator can be used for cleaning inside the plant. This reduces clean water demand. The water can be temporarily stored in a tank until required for cleaning.

6.2.3 Water Conservation

If the recovery process in (b)(i) below is carried out, which involves pressing waste to extract oils, 50% of free water in peel is squeezed out and the bin is emptied under piston press. Water used for cleaning peel bin is reduced to less than 2m³/day.

6.2.4 Boiler Feed water

Feed water into boilers need to be reduced to 20% of current volumes and energy supplied to match these volumes. Excess hot water from the boiler should be redirected to the liming tank so as remove limonene from liquid waste.

6.2.5 Pond water for irrigation

Water from pond number 8 and 9 can be used for irrigating both citrus plantations and horticultural fields. It is possible to irrigate citrus fields with citrus plant wastewater (Koo). This can avoid the overloading of ponds during the rain season and allows the dewatering of ponds successively in order to allow maintenance activities to be done while ponds are dry. Reduction in pond volumes eliminates water overflow over the pond banks thus curbing the discharge of semi-treated waste from the first ponds.

7. SOLID WASTE

7.1 Peel waste

7.1.1 Recycling of whole fruit

Whole fruit falling from the sizer can be picked by hand and put back into washing tank and not swept as waste material into the drains.

7.1.2 Recovery of the citrus oil and sugars

The peel waste from the juicing process is recovered in dry form as a high protein stock feed. To achieve the required degree of dryness, the peel requires pressing giving a yield of liquid pressings which is currently discharged as effluent. This effluent contains high levels of citrus oil and sugars, which contribute significantly to the waste loading of the effluent, particularly BOD.

The cleaner production initiative is based around recovery of the citrus oil and sugars from the liquid pressings. A motorized screw press can be incorporated on the peel bin and a liquid collecting tank connected to store the liquid press.

Citrus oil from the pressings is recovered using centrifuges and polishers to recover the oil from a water/oil emulsion. This can achieve yields of 3.5 to 4 litres of oil per tonne of citrus fruit processed. To enhance the value of the recovered citrus oils, oil can be separated by type (e.g., orange, lemon, etc) and by grade, rather than bulk citrus oil, by fractional distillation process.

The presence of citrus oil in the effluent stream inhibits microorganisms responsible for the breakdown of waste at the WSPs. Removal of the citrus oil improves the operation of any downstream treatment operations. In addition, the citrus oil is itself a valuable product, which is used as an industrial cleaning agent. The recovery of sugars as molasses can eliminate a significant contributor to the effluent BOD levels.

The recovery and sale of citrus oil can be a significant source of additional revenue.

7.1.2 Liquor production

After recovery of citrus oil, the effluent is processed through a vertical tube evaporator, which concentrates the liquor to produce a sugar-rich material (fruit molasses). Molasses is suitable as an on-farm additive to cattle feeds.

Since the function of the peel bin has changed to peel oil peel extraction chamber, water supply to the bin is only required to wash the empty bin. This requires a maximum of 2 000L/day. Thus fresh water demand is reduced.

Liquor production does not require extra equipment. Existing installations are used but would require extra piping and process optimization.

7.1.3 Animal Feed from peel residue

Animal feed can be developed from the following flow chart:

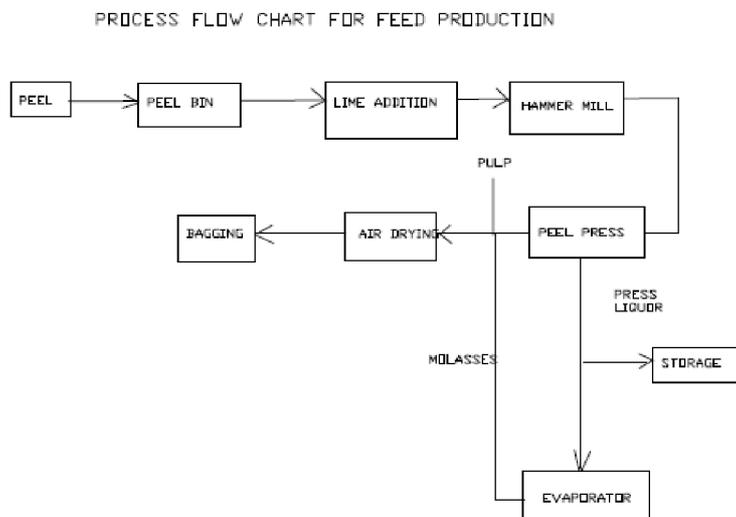


Figure 4: Process flow chart for feed production

When the liquid press has been extracted, the peel can be quickly sun dried without the risk of decaying and changing the soil chemical structure due to liquid extracts. The whole peel combined with the pulp residue and/or molasses can be used as feed for animals. Citrus peel is suitable for inclusion in ruminant diets because of the ability of ruminants to ferment high fibre feeds in the rumen (Grasser et al., 1995). This is a relatively low cost feed material. that reduces feed costs, while maintaining high productivity. This is a low cost waste disposal compared to land filling and using peel as soil amendments.

Pressing out liquid from fresh citrus peel can reduce transportation, storage and handling costs because of its high moisture content. Removal of sugars inhibit secondary fermentation, mold growth as well as attracting flies, and its wet and sticky nature which makes it difficult to store in sheds, bunkers or silos.

There is potential to produce X tonnes of citrus peel feed.

7.1.4 Seeds

Can be separated from the peels to produce seed oils, seed meals and dried seed pressed cake. This can also be collected collectively with peel waste, dried and used as animal feed.

1. LIQUID WASTE

8.1 Recycling of less than 30 % Brix

Since 500L/day of less than 30% Brix is discharged as effluent, its recycling for further concentration to required brix concentration would totally eliminate the discharge of low % brix and its associated low pH, high BOD and COD. This requires the installation of a temporary storage tank into which low brix concentrate is discharged from the evaporator. The temporary storage tank will discharge the low brix concentrate to the evaporator continuously until the required concentration is reached. Recommended temporary storage tank capacity is 1 000L.

8.2 Pulp (principal edible portion, endocarp)

This can be added to peel and uniformly mixed before drying.

8.3 Waste waters (aqueous effluent emulsions from processing plants)

Wash water from the peel bin, plant floor, wash water from evaporator and pasturiser can be collected and used in the production of activated sludge.

9. EFFLUENT CONVEYANCE SYSTEM DESIGN

9.1 Drainage system Design

Drainage pipe from the laboratory needs to be diverted to liming tank so that it does not discharge straight into the river. This ensures the treatment of waste before discharge into river. Discharge (wash water) from the peel

9.2 Liming Tank

The capacity of the liming tank needs to be increased from a waterway depression of 0.2m³ to a 500 m³ mixing tank which allows all the day's effluent to be limed to pH 6-8.

10. MAINTENANCE MANAGEMENT SYSTEM

There is need to develop a plant maintenance management system for both the process plant and the waste treatment plant. The spilling of concentrates and fruits and water leakages on the floor is an indication of at least failure to adhere to the MMS or at worst its absents.

11. CONCLUSION

The cleaner production options discussed involve new technology, plant process modification and maintenance work. A combination of interventions are required to address the environmental problems resulting from current dumping practices The new technology and process modification ensure the further processing of waste products into salable products.

Effluent segregation unearthed that plant processes are responsible for the discharge of most of environmentally degrading waste that include whole fruit, partially expressed fruit, peels, seeds, pulps, laboratory chemicals, dilute juice extracts and water.

There is potential to increase product varieties if by-products, which are regarded as waste are further processed by adding a few unit operations and in the process eliminating the negative impacts of factory waste.

Most of the waste damaging the environment comes from poor decision making, design and ineffective plant maintenance management systems. Poor plant management practices are also the major cause of sub-optimal plant performance. Underperformance of machinery due to leaking and low efficiency (e.g. fruit sizer and extraction machine) indicate poor maintenance management strategy. The release of partially treated waste is a cause of poor pond maintenance management system and poor design of effluent system. The accumulation of natural vegetation in WSPs clogs the ponds and interferes with the natural biological processes because of poor water dynamics, aeration and lighting.

Although there exists policies guiding the safe disposal of waste in Zimbabwe, there lacks policing such that many industries discharge harmful waste without due regard to the environmental effects or taking measures to reduce the effects.

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Authors' Profiles



Special Musoni did BSc in Agricultural Engineering in 2007 and MSc in Manufacturing Systems in 2010 at the University of Zimbabwe, (UZ) . He worked as a teaching assistant at the UZ since 2007 to 2011 and as a lecturer since 2011 to date in the Department of Agricultural Engineering where he teaches Systems Engineering, Process Engineering and Quantitative Methods. He undertook and published research in Mechanization Engineering and energy in technical journals.



Kumbi Mugwindiri, did Bsc Mechanical Engineering Honours at the University of Zimbabwe, and Masters in Manufacturing Systems at Cranfield University, England. Currently, lecturing Engineering Management at the University of Zimbabwe. Worked as Workshops Engineer for Zimbabwe Phosphates Industries responsible for heavy maintenance of process plant equipment . In 1993 carried out a project with the Ford Motor Company to determine ways of improving working patterns and practices, this was a European Union wide project. In 2000, he undertook collaborative research in Clean Technologies at Tulane University in New Orleans. Has worked with many organizations researching/and or consulting in Maintenance Engineering and Cleaner Production