Limit environmental damage by basic knowledge of coffee waste waters

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Environmental issues are coming more and more into public discussion, in Vietnam and internationally. They are also becoming more relevant to the Vietnamese coffee sector as the new plans of the government are to widen the production of high quality wet processed Arabica coffee. It is important to be aware of the potentially detrimental environmental effects caused by the liquid and solid by-products of wet and semi-wet coffee processing and identify ways to overcome these problems.

Characteristics of coffee waste water

The waste waters from wet coffee processing can be basically divided into two parts. Firstly, the pulping water with a high content of quickly fermenting sugars using enzymes from the bacteria on the coffee cherries. Secondly, depending on the processing method applied, the water from fermentation/washing or the thick effluents from the mechanical mucilage removers.

The main pollution in coffee waste water stems from the organic matter set free during pulping, particularly the difficult to degrade mucilage layer surrounding the beans. The mucilage contains mainly proteins, sugars and pectins. The pectins make up the gel like constitution of the mucilage by polymerising Galacturonic acid made from sugars.

The sugars contained in the mucilage will quickly ferment to alcohol and CO_2. However, in this situation the alcohol is quickly converted to vinegar or acetic acid in the fermented pulping water.

The waste water from demucilators contains a certain amount of sugars, but its apparent thickness comes from the chunky segments of raw undigested mucilage which has been ripped off the beans by mechanical means. This solid material has to first be fermented and solubilised.

The wash waters from conventional processing in fermentation tanks, appears to be much less concentrated because of the already solubilised non chunky mucilage.

Composition of mucilage...

Water	84,2%
Protein	8,9%
Sugars	
- Glucose (reducing)	2,5%
- Sucrose (non reducing)	1,6%
Pectin	1,0%
Ash	0,7%

Composition of coffee pulp...

Ether extract	0,48%
Crude fibre	21,4%
Crude protein	10,1%
Ash	1,5%
Nitrogen free extract	31,3%
Tannins	7,8%
Pectic substances	6,5%
Non reducing sugars	2,0%
Reducing sugars	12,4%
Chlorogenic acid	2,6%
Caffeine	2,3%
Total caffeic acid	1,6%

Other substances to be found in coffee waste water are toxic chemicals like tannins, alkaloids (caffeine) and polyphenolics. These components make the environment for biological degradation of organic material in the waste water more difficult.

During the fermentation process in the waste water, the acidification of sugars will drop the pH to around 4 or less, and the digested mucilage will be precipitated out of solution and will build a thick crust on the surface of the waste water, black on top and slimy orange/brown in colour underneath. If not separated from the waste water, this crust will quickly clog up waterways and further contribute to anaerobic conditions in the waterways.

Effects on the Environment

The organic and acetic acids from the fermentation of the sugars in the mucilage make the wastewater very acid (pH down to 3.8). Under these acid conditions, higher plants and animals will hardly survive.

After the first fermentation of sugars in the waste water took place, the organic substances diluted in the waste water break down only very slowly by micro-biological processes using up oxygen from the water. This process causes problems as the demand for oxygen to break down organic material in the waste water exceeds the supply, dissolved in the water, thus creating anaerobic conditions.

Values for Biological Oxygen Demand (BOD) indicating the amount of oxygen needed to break down organic matter in coffee waste water are high (up to 150 g/l for effluents from demucilators). However, the very slowly degrading compounds indicated by the Chemical Oxygen Demand (COD), make up around 80% of the pollution load and are reaching 40 g/l and more. Luckily most of this material can be taken out of the water stream as precipitated mucilage solids and made into compost.

Biological Oxygen Demand (BOD)...

… defines the amount of oxygen needed to biologically break down organic wastes diluted in water. Some typical values:

- Distillery wastewater: ≈100 g/l
- Paper Mill wastewater: ≈10 g/l
- Meat-works wastewater: ≈2 g/l
- ***Coffee waste water: ≈150 g/l***

As an effect of the high values of COD and BOD anaerobic conditions ("rotting") set in quickly causing bad smells and speed up the death of aquatic life due to the quick use up of oxygen dissolved in the water. Bacteria living in anaerobic conditions can also cause health problems fur humans when found in drinking water.

In addition to the bad smell, coffee waste water will turn dark green to black after a while. This discoloration is caused by the chemical components of the red colour of the coffee cherry (flavanoids) and is also known in other food processing industries, like the wine and olive industries. These fruit colours are actually the precursors of the brown humus colour of swamp water, which is completely innocuous to aquatic species. So, although they do not look nice, the intermediate black colours by themselves do not do any harm to the environment nor add much to the BOD or COD.

Summarising, the combination of high acidity, and high BOD, depleting life supporting oxygen from the water, is causing the problems in coffee waste water treatment and need to be overcome.

A matter of quantity

In general, factories which try to practise some form of water conservation can usually get their water usage down to around 6 cubic meters per tonne of cherry or less.

In general, the fully washed method with no recirculation of water and an included fermentation step requires more water than the process of mechanical mucilage removal producing semi-washed coffee. In practice, 1 to 15 m^3 of fresh water per tonne cherry have been reported from international sources.

Most of the Vietnam Arabica coffee is processed in a centralised way by mechanical mucilage removal. The centralised setup of processing lines produces medium quantities of highly polluted waste waters for around 4 months in the year. Waste waters are normally discharged untreated into small waterways causing serious environmental problems.

Amounts of water used for processing (per t cherry)

- **Kenya**, fully washed, of processing water
→ around 4 to 6 m^3
- **Columbia**, fully washed and environmental processing (BECOLSUB):
→ between 1 and 6m^3
- **Papua New Guinea**, fully washed, recycling of use water
→ between 4 and 8 m^3
- **Vietnam**, semi-wet and fully washed:
→ between 4 and 15 m^3

In order to be able to control the problem of waste water, the first step must be to keep the amount of effluents as small as possible to be able to treat the water in an appropriate way without requiring too much space for ponds, etc. Therefore, the recycling of used water, e.g. from pulping, is strongly advised for both fully washed and semi-washed coffee. However, water recycling requires skilled labour in order not to damage coffee quality!

Control measures – acidity

The acidity of untreated water needs to be lifted to at least pH 6 or 7, before discharge into natural waterways without threatening aquatic life.

Considering the low cost and ease of supply of natural limestone, $CaCO_3$, it seems the best solution to neutralise coffee waste water. After good mixing of limestone and acid water, the pH of the coffee waste water will automatically stabilise at a pH of 6.1 leaving any excess limestone unchanged. Burnt lime, (Calcium Oxide, CaO) and slaked limestone or Calcium hydroxide ($Ca(OH)_2$) are not appropriate as they are not automatically buffering, and the danger to create excessively alkali conditions with too high pH values is too great.

It is advised to mix finely ground limestone thoroughly with clear-yellow acid water, ideally with the help of a pump, in order to speed up the buffering process. In theory, 250 mg of limestone is needed to buffer 1 litre of acid water. The practice, however, suggests that the amount needed is higher because the neutralisation of acid water needs to be as quick as possible and the higher the amount of limestone available for neutralisation, the quicker the reaction time for neutralisation.

Before mixing raw waste water with limestone, it must be made sure, that the sugars in the waste water have been fully acidified and the raw mucilage has come out of solution. This should happen in a pond where the water is allowed to rest at shallow depths for at least 6 hours. This pond must be regularly cleaned from the floating mucilage and sediments in order to keep up the maximum storage capacity.

If acidification is not allowed sufficiently, any further treatment will meet great difficulties as the mucilage will get out of solution at later treatment stages and will quickly clog up filters, ponds and more especially biogas digesters.

Control measures – high organic matter loadings

Although the water below the slimy crust of mucilage on the acidification pond appears clear, that water is very acid and still high in BOD and COD. After the water has been neutralised, as described above, the remaining organic material in the water needs to be broken down. The BOD should be reduced to less than 200mgs/L before let into natural waterways.

There have been many approaches in coffee producing countries to get the pollution load under control. Anaerobic settling ponds, artificial aeration, biogas reactors, land application by irrigation or wetlands are used. However, the toxins, the extremely high BOD and COD and the high acidity still make the treatment a complicated of coffee waste water difficult.

Post Harvest Processing
Arabica Coffee

Waste Water type	*Required action*	*Installation*	*Remarks*
Raw effluents from processing (recycled water, demucilator effluents, fermentation tank effluents)	**Fermentation, Acidification and sedimentation** of mucilage and pulp components diluted in the water	Long and shallow acidification tank	During acidification, a thick crust of raw mucilage will build up floating on the water. The middle layer is clear acid water, sediments will settle to the bottom. Regular cleaning is required.
Clear Acid water from acidification tank	**Neutralisation** with limestone ($CaCO_3$) to pH 6	Mixing tank with trash pump	Use powder or finely ground limestone.
Neutralised water (pH around 6)	**Reduction of BOD and COD**, consumption fertilising salts from reaction between acid and limestone (calcium acetate)	- Biogas digester - Wetland planted with reeds and rushes - Anaerobic settlement pond - Artificial aeration	Depending amount of discharge water of the factory, the most suitable options is to be chosen.
Pre-treated waste water	**Final cleanup** of water	- Wetland planted with reeds and rushes - Water hyacinth pond - Final settle and infiltration area	Acidity and BOD/COD are under control, however water might still be dark green to black in colour.

The economics of waste water treatment

Coffee processors will not adopt any waste water treatment installations if the costs of implementation will exceed the benefits. In other coffee producing countries, environmental laws are being enforced strictly and high penalties are to be paid when exceeding legal thresholds for effluents. This forces processors to implement waste water treatment measures.

Costs for waste water treatment relate mainly to construction and to labour costs for managing the installations. The coffee processor needs to keep the costs for construction as low as possible and needs to look for possible income from generated waste.

Pilot Waste Water Treatment Plant

At the project site in Khe Sanh, Quang Tri, a pilot waste water treatment system is presently under construction. At times of peak production, around 100 tonnes of fresh cherry are processed. Effluents reach to 400m^3 a day and are treated in an acidification tank before neutralisation of the acid water takes place.

Presently, a pilot biogas plant is in planning which will reduce up to 90% of BOD content and deliver up to 1 litre methane per litre neutralised waste water. However, to make good biogas at a low pH of 6.1 of waste water, a special strain of methanogenic bacteria, developed especially for the Khe Sanh project, to metabolise calcium acetate, is needed. The methane thus formed will be used for partial substitution of coal for drying.

For secondary treatment, a constructed wetland is being designed in cooperation with the Technical University of Hanoi. The rushes and reeds will raise the dissolved oxygen levels by pumping air down into their root zones through their hollow stems, and remove some of the remaining nutrients from the biogas digester effluent. Tertiary treatment and final cleanup will be done by water hyacinth ponds.

The positive economics in this case are hoped to be achieved by reducing cost for coffee drying. This is a major factor in the wet conditions in Khe Sanh during processing times. Secondary and tertiary treatment is carried out by biological means requiring very low maintenance and operating costs.

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