REVIEW OF COFFEE WASTE WATER CHARACTERISTICS AND APPROACHES TO TREATMENT

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ABSTRACT

Wet processing of Arabica coffee (Coffea Arabica) produces higher quality and receives higher prices on the world market compared to coffee prepared via dry method. Behind the background of depressed world market prices, countries with comparatively low production costs like Vietnam will increasingly switch their production to high quality and higher priced washed Arabicas in order to enhance competitiveness and revenues.
However, wet coffee processing requires a high degree of processing know how and produces large amounts of processing effluents which have the potential to damage the environment. Characteristics of waste water from coffee processing is a Biological Oxygen Demand (BOD) of up to 20.000 mg/l and a Chemical Oxygen Demand (COD) of up to 50.000 mg/l as well as an acidity of below pH 4. In order to treat coffee processing waste waters, the constitution of waste water is presented and technical solutions for waste water treatment in a pilot case are presented.

Keywords: Washed Arabica coffee processing; coffee waste water; waste water treatment

INTRODUCTION

Coffee is a valuable trading good which is produced in the tropics and mainly consumed in Europe and the United States. Arabica (*Coffea Arabica*) and Robusta (*Coffea Canephora*) are the two varieties which are internationally traded. Arabica receives higher prices due to more favourable taste characteristics and makes up 61% of the world production (Deutscher Kaffeeverband 2001). Robusta coffee is an important component of commercial coffee blends due to its characteristics of a rich "body"[1] (Viani, no date). Brazil is dominating the world market as it is the biggest Arabica coffee producer. For Robusta, Vietnam is presently the biggest producer, however, the picture is expected to change as Brazil is likely to overtake Vietnam during the 2002/3 crop season (NKG Statistical Unit Quarterly Report 2002).

Coffee world market prices are presently in a severe crisis as the market suffers from oversupply (Deutscher Kaffeeverband 2001) which is not seen to change in the near future (NKG Statistical Unit Quarterly Report 2002). Current price levels make it difficult for many coffee producers to generate profits as their costs exceed world market prices (FAO 2002). The only way to receive an optimum price even under the present market scenario, appears to produce high quality Arabica coffee.

Behind this background, countries with competitive labour costs and feasible natural conditions like Vietnam, aim to make their marginal profitable coffee sector more viable by changing production partly to the more profitable washed (or wet) processed Arabica production (VICOFA 2002). This processing method, however, requires a high degree on knowledge in processing and has a large potential of polluting surface waters from processing effluents (Mburu 1999), especially when processed in centralised manner.

COFFEE PROCESSING

After picking of coffee cherries, the fruit has to undergo several processing steps in order to remove the outer parts of the fruit, i.e. skin (exocarp), pulp (mesocarp), the mucilage layer and the endocarpal parchment (see Fig. 1) The

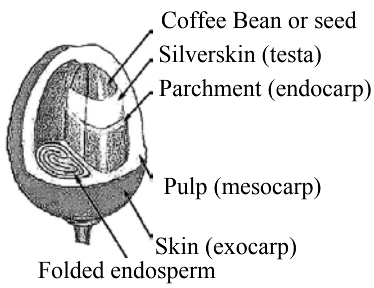

Figure 1. Morphology coffee cherry (after Rothfos 1979)

[1] Body is the viscosity, fullness and weight in the mouth of a beverage, ranging from "thin, watery" to "thick, heavy" (Viani, no date).

way of processing determines the quality of the end product. In addition, each processing technique has a different pollution potential.
The most simple and least polluting way of processing is the dry method, which is mostly applied for Robusta coffee but also for a large amount of Brazil Arabicas (Adams et al 1987). In this method, cherries are picked and left in the sun until the whole fruit reaches a moisture content of around 11%. After drying, the outer flesh and parchment is removed in one step.
In contrast to the dry method, wet processing requires a higher degree of processing know how and is applied mainly for Arabica coffee (Vincent 1987). Wet processing is producing a higher quality product, so called “mild coffees”. The finer quality is due to a pre-sorting step of cherries which only allow ripe cherries in the process (Fig. 2). During processing, exocarp and coffee pulp (mesocarp) are mechanically removed before the gelatinous and hygroscopic mucilage cover, which is coating the parchment, is removed. This is done during an approximate fermentation time of 36 hours depending an natural conditions like altitude and temperature (Rothfos 1979). Only after the mucilage layer has been hydrolysed, all residues are washed off and the clean parchment is ready for further processing, i.e. drying and hulling (Vincent 1987).

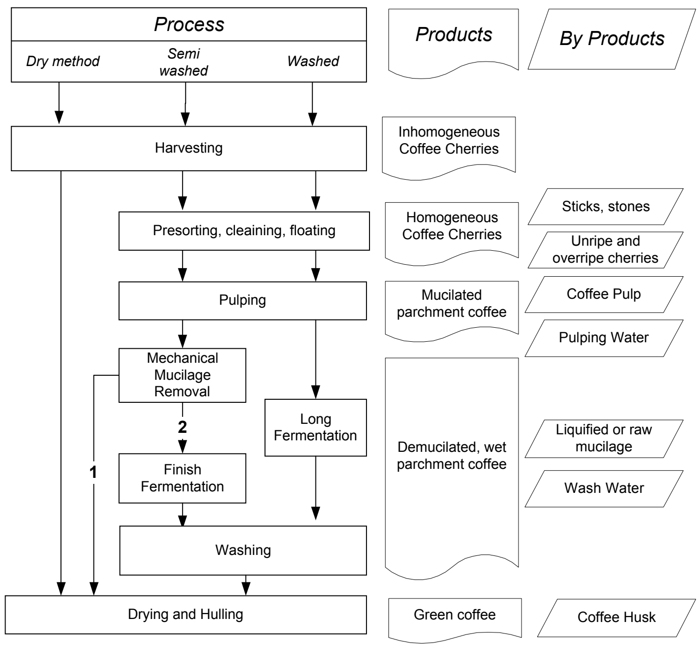

Figure 2: Coffee processing methods

The semi-wet or semi-washed process[2] is similar to the wet or washed process. During semi-wet processing, however, the time consuming fermentation step is reduced as the mucilage layer is removed mechanically. After the mechanical removal of the mucilage, the wet coffee should ideally undergo a shortened "finish" fermentation to fully remove remaining mucilage from the parchment followed by washing/soaking in order to produce an optimal quality. Somewhat lower taste characteristics have been found when freshly demucilated coffee has been sent directly into driers (Becker 1999).

WASTE WATER CHARACTERSITICS

The environmental impact of wet and semi-wet processing is considerable. Problems occur through large amounts of effluents disposed into watercourses heavily loaded with organic matter rather its than inherent toxicity (Adams et al 1987). Providing the self purification of the watercourse is exceeded, the microbial degradation reduces the level of oxygen to anaerobic conditions under which no higher aquatic life is possible.

Water Quantities

Depending on the processing technology applied, quantities of coffee waste water is varying. Modern mechanical mucilage removal machines producing semi-washed coffee use only about 1 m^3 per tonne fresh cherry (without finish fermentation and washing) whereas the traditional fully washed technique without recycling uses up to 20 m^3 per tonne cherry (Mburu et al, 1994). In order to treat waste water properly and at reasonable costs, the amounts of waste water must be minimised.

Organic Components

The main pollution in coffee waste water stems from the organic matter set free during pulping when the mesocarp is removed and the mucilage texture surrounding the parchment is partly disintegrated (Mburu et al 1994). Pulping water consists of quickly fermenting sugars from both pulp and mucilage components. Pulp and mucilage consists to a large extend of proteins, sugars and the mucilage in particular of pectins, i.e. polysaccharide carbohydrates (Avellone et al, 1999).

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[2] No clear definition for semi-wet or semi-washed is available. In this context, it will be used for the process of mechanical mucilage removal. In Spanish the word "desmucilaginado" is used. Aquapulping has also been used, however, it describes an entirely different processing method in which pulping and demucilating is done in a one step process.

Depending on the processing method applied, further waste water evolves in the form of hydrolysed pectins from fermentation and washing. During fermentation, long chain pectins are split by enzymes (pectinase, pectase) into short chain pectin oligosaccharides. Oligosaccharides are soluble in alkaline and neutral solutions, but in acid conditions they are thrown out of solution as Pectic acid. (Rothfos 1979, Treagust 1994). In the presence of calcium or other multivalent ions, the pectic acid fragments are cross linked into a non-soluble gel of calcium pectate (Treagust 1994).

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%

Table 1: Composition of coffee pulp (Gathuo et al 1991)

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

Table 2: Composition of mucilage (Clifford and Wilson 1985)

Waste water from mechanical mucilage removers contains a certain amount of sugars (disaccharide carbohydrates), but its apparent gel like texture comes from the segments of undigested mucilage and pectic substances which have been removed from the parchment by mechanical means. In order to be biodegraded, the solid materials have to be fermented, acidified and hydrolysed by natural fermentation in a later stage.

During fermentation and acidification of sugars in the waste water, pectin oligo-sacharides get out of solution and float on the surface of the waste water. The remaining highly resistant materials left in the effluent water are acids and flavanoid colour compounds from coffee cherries. At around pH 7 and over, flavanoids turn waste water into dark green to black colour staining rivers downstream from coffee factories. However, flavanoids do not do any harm to the environment nor add significantly to the Biological Oxygen Demand (BOD) or Chemical Oxygen Demand (COD).

Values for Biological Oxygen Demand (BOD) indicating the amount of oxygen needed to break down organic matter are high in coffee waste water (up to 20.000 mg/l for effluents from pulpers and up to 8.000 mg/l from fermentation tanks). The BOD should be reduced to less than 200 mg/l before let into natural waterways.

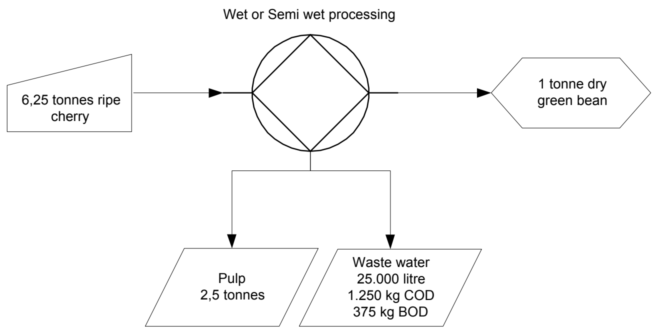

Figure 3: Mass balance coffee processing

Resistant organic materials which can only be broken down by chemical means indicated by the Chemical Oxygen Demand (COD) make up around 80% of the pollution load and are reaching 50.000 mg/l and more (Treagust 1999). The material making up the high COD can be taken out of the water as precipitated mucilage solids. Other substances to be found in small amounts in coffee waste water are toxic chemicals like tannins, alkaloids (caffeine) and polyphenolics. However, these toxic substances mainly stay in the disposed solids of the coffee pulp.

Acidity

During the fermentation process in the effluents from pulpers, fermentation tanks and mechanical mucilage removers, sugars will ferment in the presence of yeasts 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 simplified chemical formula for biological fermentation of 6 carbon sugars by yeasts to ethanol is typified by the fructose to ethanol reaction:

$$C_6H_{12}O_6 = 2\ CH_3CH_2OH + 2\ CO_2 \quad (1)$$
$$\text{Sugar} = 2\ \text{Ethanol} + 2\ \text{Carbon dioxide}$$

Ethanol is quickly broken down by bacteria into acetic acids. This complex enzymatic catalysed reaction is simplified as

$$2\ CH_3CH_2OH + O_2 = 2\ CH_3COOH \quad (2)$$
$$2\ \text{Ethanol} + \text{Oxygen} = 2\ \text{Acetic acid}$$

The acidification of sugars will drop the pH to around 4, 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.

APPROACHES TO WASTE WATER TREATMENT

At the project site in Khe Sanh, Quang Tri, Vietnam, a pilot waste water treatment system is presently under design and testing for semi-washed coffee including finish fermentation and washing. At times of peak production, around 100 tonnes of fresh cherry are processed. Average water consumption has been brought down from over 10 m^3/tonne cherry to around 4m^3/tonne cherry processed through recycling and reuse of processing waters. Total effluents reach 400m^3 a day at peak times.

The treatment system consist of an acidification pond (200m^3), followed by a neutralisation tank (25m^3) filled with ground limestone. After neutralisation of waste water to pH 5.9 to 6.1., water is treated alternatively in a Upflow Anaerobic Sludge Blanket (UASB) biogas reactor before entering a constructed wetland planted with macrophytes for secondary treatment. For tertiary treatment, waste water runs through a water hyacinth pond for water polishing before entering the open waterway.

In the acidification pond, effluents from mechanical mucilage removers as well as the recycled processing (pulping, pre-sorting, washing) water is allowed to rest at shallow depths for at least 6 hours. During this time, raw mucilage comes out of solution and will float on top ready to be raked off. The acidity of untreated acid water below the crust needs to be lifted to at least pH 6 before further treatment can take place Considering the low cost of natural limestone ($CaCO_3$) automatically buffering at 6.1, limestone seems the best solution for stabilisation. In theory, 250 milligrams of limestone is needed to buffer 1 litre of acid water (Treagust 1999). In the presence of limestone, the acetic acid is converted to calcium acetate with a radical change in solution pH from 3.8 up to 6.

$$2CH_3COOH + CaCO_3 = Ca(CH_3CO_2)_2 + CO_2 + H_2O \quad (3)$$

Acetic Acid + Limestone = Calcium Acetate + Carbon dioxide + Water

During primary water treatment, neutralised waste water is used as feedstock in an UASB biogas digester working on a special strain of methanogenic bacteria from coffee plantation soils. The bacteria are active at a pH of around 6 at ambient temperatures. In the process of anaerobic decomposition, bacteria metabolise dissociated acetate ions which is the reaction product of Calcium Carbonate ($CaCO_3$) and acetic acids (2HAc) in the neutralised waste water.

$$2\ CH_3COOH = 2CH_4 + 2\ CO_2 \quad (4)$$

2 Acetic acid = 2 Methane + 2 Carbon dioxide

During biogas operation, a reduction of 70 to 90% of BOD content can be achieved in as little as 4-6 hours retention time (Calvert 1999, Vinas et al 1988) delivering around 5 m^3 methane per tonne cherry processed (Calvert 1999). Presently, the prototype biogas digester in use has a capacity of only 5 m^3 and is able to process about 20 m^3 neutralised waste water per day leaving an access amount of acetate effluent be lead directly into the constructed wetland. Methane resulting from UASB digestion can be reused for fuelling coffee driers and contributes to the reduced energy costs for post harvest processing costs

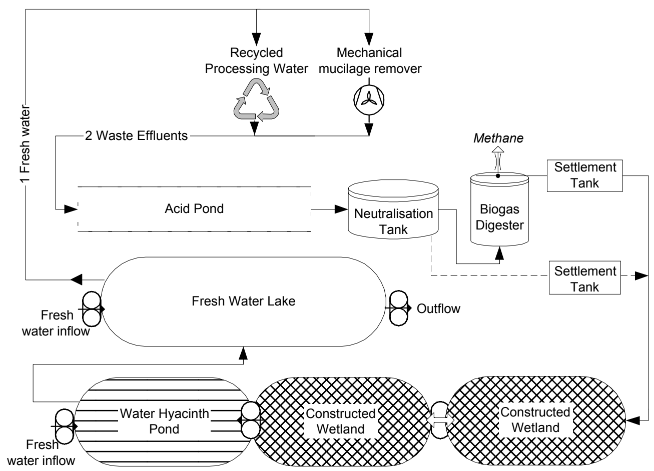

Figure 4: Planned pilot waste water treatment setup

	Acid Pond (In)	Neutrali-sation Pond	UASB Digster	Settling Tank.	Wet-land	Hyacinth Pond	Out-let
PH	3,8	6.1	6.1	6.5	6,5	7	7
BOD mg/l	20,000	10,000	1,000	800	<400	200	<200
Reduction in BOD	50%	Minor	90%	20%	50 %	50%	

Table 3: Estimated efficiency of waste water treatment system

Secondary treatment is done in a constructed wetland planted with rushes and reeds (*Phragmitis australis*) following the design of an emergent macrophyte treatment system with subsurface flow (Vymazal et al 1998). In this treatment method, dissolved oxygen levels in the water are increased through diffusion of oxygen in the root zone of the macrophytes growing in the flooded gravel bed. The additional oxygen supplied is speeding up the aerobic decomposition of remaining organic matter. The water levels in the wetlands may also be artificially raised and lowered to assist the oxygen flow. In addition to aerobic bacteria active close to the roots of the plants, anaerobic decomposition can also take place in a wetland. A construction of wetland is able to remove up to between 49 and 81% BOD loadings and lower the amount of suspended solids between 36 and 70% depending on initial BOD loadings and retention time (Biddlestone et al 1991). In addition, macrophytes remove nutrients and salts from biogas digester effluents.

Tertiary treatment and final cleanup will be done by water hyacinth (*Eichornia crassipes*) ponds. Water Hyacinth are particularly active in the removal of both bacteria and heavy metals. In addition, fresh water inflow into the water hyacinth pond dilutes the organic loadings.

SUMMARY

Coffee waste waters are high in organic loadings and exhibit a high acidity. When washed or semi washed coffee is processed in large quantities, untreated effluents greatly exceed the self purification capacity of natural waterways. In order to overcome the pollution potential of processing waste waters, a clear understanding of waste water constitution in inevitable to design a feasible treatment system. Especially when expanding wet coffee processing or setting up new large scale processing operations, treatment of waste waters needs to be considered.

Firstly, the amount of sedimentable solids contributing to COD loading of waste water need to be lowered. This is achieved during a sufficient time of acidification of sugars present in the waste water during which solids get out of solution. After full acidification, the clear, acid waste water is treated by natural limestone to lift the pH from around 4 pH to a pH to around 6. Only at this pH levels, UASB digestion and constructed wetland will achieve optimal results.

The UASB technology is central in the treatment process as the highest reduction of BOD levels in relatively short times are achieved. Effluents from the UASB digester are high in phosphates and still reveal a BOD which needs to be treated in secondary treatment. Secondary treatment and consumption of phosphates is accomplished in a locally adopted constructed wetland using macrophytes to alter aerobic bacterial decomposition of organic matter. Before disposed, waste water tertiary clean up and dilution of BOD loadings is achieved by leading waste waters through a pond of water hyacinths. Only after this multi step clean up, water is safe to re-enter natural waterways.

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