MAURITIUS RESEARCH COUNCIL
INNOVATION FOR TECHNOLOGY

STUDY OF EFFLUENT TREATMENT IN MAURITIUS

Final Report

February 2000

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ABSTRACT

This project aims at identifying and quantifying the activities of dyehouses in Mauritius. Cotton fabric dyeing is, by far, the main wet processing activity. Reactive dyes and salts are the main chemicals in use. A survey of all dyehouses in Mauiitius was undertaken to obtain precise data of their operations.

The characteristics of a number of the important parameters of effluent were determined. It was found that BOD, COD and heavy metals' content were in general well above the consent limits.

A detailed analysis of the treatment practices was also carried out. It has been observed that effluent treatment, in general, though very costly, was not effective in bringing down the level of BOD, COD, heavy metals and other parameters below the consert limits.

Finally, taking into consideration, the activities of dyehouses, the characteristics of effluent and treatment practices, a number of measures have been proposed. These measures aim at reducing the impact of dyehouses activities on the environment.

MILESTONES

1. Cotton fabric dyeing constitutes the major activity in dyehouses in Mauritius
2. The most widely used dyestuff belongs to the reactive dye class.
3. Salt is, by far, the most important chemical used.
4. Raw dyehouses effluent parameters are consistently well above the consent limits. This is irrespective of region, processing activities; raw materials used and discharge points.
5. Treatment practices, in general, are not effective in bringing down effluent parameters below the consent limits.
6. The main threat to the environment from dyehouses is the heavy metal content of effluent. Major effort has to be put in, urgently, to tackle this problem.
7. Modification of processes, employee training and education, proper equipment maintenance, application of new technologies are just a few important measures that companies need to consider and implement to minimise the effect of dyehouses on the environment.

Chapter 1

INTRODUCTION

Over the past 25-30 years, the textile industry has evolved into a key component of the Mauritian economy. It is the largest of all the manufacturing industries beth in terms of workforce and domestic export value. It employs around 70,000 people and in 1998, generated revenues of about 25 billion Rupees. At present, the total exports of textile and clothing represent an impressive 61 % of our total exports [1].

In 1970, the Export Processing Zone (EPZ) scheme was implemented in Mauritius to revive the economy, particularly by encouraging foreign investment. Following the introduction of both fiscal and non-fiscal incentives, and with the arrival of [nternational Trade Agreements such as the LOME Convention and the MFA, the textile industry, in the presence and abundance of cheap labour, developed to become a major force in the economy.

In consequence, the vertical integration of the textile industry was inevitable and it triggered, among other developments, the setting up and expansion of dyehouses in Mauritius both within and outside industrial zones. The number of dyehouses increased from six in 1984 to thirty-four in 1998. However, this growth has not been without its effects on the environment although environment protection laws have constantly evolved over the past thirty years.

The textile industry is a large consumer of water and the Central Water Authority (CWA) has estimated that the wet processing industry consumes about 30 % of all the water used (excluding domestic and agricultural usage). The textile finishing industry in Mauritius, as elsewhere, represents a major potential threat to the environment both in terms of the volume and nature of the untreated effluent.

Environmental protection is a perpetual and growing concern both nationally and internationally, as the impact of human activities on the habitat becomes better understood. Almost all sectors of economic activity are potential polluters and each sector has an obligation to take every step possible to protect and preserve the environment.

Textile industries, both old and new, are being compelled to treat their effluent to such an extent that it does not cause any deleterious effects on the water quality when it is discharged into receiving waters. This remains a great challenge to many well-established wet processors since most of them have already invested heavily in processes and equipment which are not environmentally acceptable to today's standard. This, of course, is bearing an important cost factor which may vary from 2-10% of the total production cost depending on the final quality of the treated water [2]. But, from a distance, it seems all very fair, sensible and justified that the polluter should pay for his act.

For long-term, sustainable development of our economy, it has become imperative that, both our water resources and textile effluent be properly and critically managed through an appropriate legal framework and with suitable, cost-effective technologies to protect the natural environment.

1.1 Textile Environmental Laws

In the early seventies, under Section 6 of the EPZ Act, no provision was made as to whether export manufacturing industries, which included the textile sector, had to set up effluent treatment plants together with their production units.

In 1989 the Central Water Authority (C.W.A.), under section 46A of its Act stated that there should not be any discharge of polluted water into inland surface waters, lagoons and underground. It was conferred the power to discontinue the supply of water to any polluter and apply fines of up to Rs.250000 or imprisonment not exceeding two years.

Two years later, the government recognised the need for a legal framework and a mechanism to protect the environment nationally. In 1991, the 'Environment Protection Act' (EPA) was legislated. It would ensure the proper implementation of governmental policies and provide the necessary enforcement policies for the protection of human health and the environment of Mauritius. Various standards such as the water and air quality standards were developed, in consultation with the relevant enforcing agencies such as the CWA. Fines would be imposed on anybody who fails to comply with any requirement issued under the Act. It was also clearly mentioned in the first schedule of the Act that the textile industry; associated with dyeing, weaving, washing, knitting, bleaching and printing, being a producer of export goods, came under this law and had, therefore, to submit an environmental impact assessment (EIA) report for its intended activities [3].

In June, the same year, one month before the EPA, another enforcing agency, the Waste Water Authority (WWA); the sole regulator of the sewer network in Mauritius, was granted the power to levy taxes on textile industries for using the sewer and to charge expenses for any related work. Also, the industry must comply with the discharge regulations and standards. Failure to comply with a notice served by the WWA would result in a fine of Rs. 100 per day for the period of non-compliance.

In 1993, under the Industrial Expansion Act of April 28, development certificate became mandatory for companies undertaking expansion or setting up new industries. The certificate was issued on the condition that anti-pollution technologies are introduced, within a period of 2 years from the date of issue of the certificate, for the protection of the environment.

Laws on environment protection have evolved considerably over the past thirty years and are getting tighter. There are guidelines for both inland surface water quality and effluent discharges. However, for the textile industry specifically, no limits on the composition of textile effluent have yet been promulgated. But work is currently being undertaken by the Ministry to establish the appropriate effluent standards.

1.2 Textile Effluent

With new and more stringent environmental laws, the textile industry is bound to face the daunting challenges of improving its present system of management and control of its effluent discharge, whether into rivers, canals, sewers or the sea.

Nowadays, the wastewater from textile mills is being disposed of in the following manner:

- Disposal into the sea, through sewers or trucks, *without treatment.*
- Discharge into municipal sewers for combined treatment with domestic sewage.
- On-site treatment of the wastewater before discharging directly or through sewers, into aquifers, rivers and sea.
- Sugar-cane irrigation after treatment.

In Mauritius, over 75% of the dyehouses discharge their untreated effluent, through the sewer, into the sea/lagoons or their partially treated effluent into rivers/watercourses or through the sewer, into the sea/lagoons. Thus, the main approach to pollution control has been either by dilution in sewers, streams or sea, or through end-of-pipe treatment.

Wastes produced by the textile industry are generally known to have a wide characteristic and polluting power profile. But research has found that the single most pressing environmental problem for the textile industry in Mauritius is related to reactive dyeing, with an average consumption of about 40-45T of dyes per month [4]. The increasing use of cotton has led to substantial growth in the usage of reactive dyes that have fixation levels varying between 50-85% industrially. As a result, the management of the spent reactive dyebaths has become a challenging and pressing problem; more so, a psychological and aesthetic problem of colour in the effluent.

According to Mackay [5], coloured organic substances generally account for a small fraction of the total organic load in wastewater but their high degree of colour is easily detectable from the aesthetic value of the watercourse. He concluded that a level in excess of 0.1 mg/l may be detectable and below 0.01 mg/l is probably non-detectable.

The other major problem of reactive dyeing is the high level of salts that may vary between 40 and 100g/L. The disturbing effects of high salinity and sulphate concentration would be discussed in more details later.

As regulations become more and more stringent, the need for more technically and economically efficient means of both colour and salt reduction from the plant effluent grows more acute. At the present time, there are no economically attractive means to achieve the reduction of these two parameters. Research work suggests the reuse of the spent reactive dyebaths but it has not yet found wide acceptance [6].

In addition to the colour and high salt level of the effluent, heavy metal concentrations beyond the acceptable limits are detected and the effects of these toxic components are discussed in later chapters.

The other obvious effect of the discharge of raw effluent or poorly treated effluent on a watercourse is the formation of foam due to the presence of surfactants. These surfactants reduce the rate of oxygen transfer at the surface of river water and may contribute to limitation of the self-purification capacity of the stream.

As for wool dyeing, the use of chrome dyes locally is assuming less importance and they have been superseded by either reactive or pre-metallised acid dyes. Thus, there is much less chances of chromium ions contamination in the effluent.

Chapter 2

TEXTILE WASTEWATERS: LIMITATIONS TO THEIR FREE DISCHARGE

2.1 Nature and Impact of Dye Effluent on the Environment

Two broad categories of textile mill processes can be identified:

(i) dry processing

(ii) wet processing.

Dry processing includes the manufacture of yarns and unfinished fabrics, while wet processing involves such sub-processes as sizing, desizing, scouring, bleaching, mercerising, dyeing and finishing which use large amounts of water.

Textile mills use a wide variety of dyes and chemicals for wet processing as discussed in Chapter 5. Many of these are not retained in the final product and are discarded in the wastewater. They would include organic chemicals, salts, surfactants, dyes, greases and oils, acid and alkaline wastes and a number of other substances. Textile wastewaters are generally characterised by high concentrations of chemical oxygen demand (COD), biological oxygen demand (BOD), suspended solids, heavy metals, extreme pH, and elevated temperatures. Foaming from detergents and dyes may cause aesthetic problems in water used for drinking and recreational purposes. Carrier chemicals used in dyeing may impart unpleasant tastes and odours to water and fish. Oil and grease and acidic or alkaline wastes can also be harmful to aquatic biological systems. In addition, many of the dyes used in textile mills are known to be mutagenic and some are suspected of being carcinogenic. Untreated textile effluents may therefore pose a hazard to aquatic life and possibly to human health [5].

2.2 Characteristics of Waste Water From Wet Processes

Table2.1

	BOD mg/L	COD mg/L	pH -	TSS mg/L	TDS mg/L	Cr mg/L	Zn mg/L	Fe mg/L	Ni mg/L	Cd mg/L	Cond mg/L
Scouring	900-3500	3000-20000	9-12	200-2000	1000-30000	71-140	0.2-0.8	0.2-0.4	.09-0.2	< DL	2-60
Bleaching	100-1600	1200-6000	8.5-11	100-500	2500-11000	150-160	0.2-0.7	0.4-0.8	0.1-0.2	<DL	5-22
Reactive Dyeing	200-300	1000-2000	9-12	200-300	600-700	300-400	0.5-0.6	0.5-0.6			1.2-1.4
Sulphur Dyeing	200-300	1000-2000	11-12	200-300	5000-6000	300-400	0.2-0J	0.2-0.3	0.8-0.9	0.2	10-12
Finishing	60-100	600-1000	5-6	40-60	300-400	80	0.11	0.12	0.07	<DL	0.6-0.8

Table 2.1 shows the effluent characteristics of major wet processes in the textile industry. Desizing, scouring and bleaching processes contribute most to the final effluent load. Consequently, appropriate remedial measures should be taken to decrease the polluting propensity of these processes. A short outline of some wet processes is given below.

2.2.1 Desizing

Desizing contributes mainly to the organic load of the wastewater and gives rise to high BOD levels, and is responsible for most of the suspended material found in effluent. Desizing operations may contribute to 50% of the total organic load in a weaving mill.

2.2.2 Scouring

Scouring process produces the strongest pollution load among all the wet processes. Scouring wastes are characterised by a high dissolved solid content; high BOD, COD, alkalinity and heavy metals. Zinc and iron are generated, from cotton processing, in particularly high amounts.

2.2.3 Bleaching

Hydrogen peroxide is mostly used as the bleaching chemical and the process contributes to about 10% of the total pollution load, with relatively high BOD, **pH** and suspended solids. Moreover, heavy metals, especially iron and zinc are present in the effluent.

2.2.4 Mercerising

Relatively negligible waste is generated from this process, with low BOD and suspended solids, but the level of alkalinity in the discharge could be high.

2.2.5 Dyeing

This type of waste alone is characterised by a high BOD and mostly alkaline pH. There is also a large concentration of hydrolysed dyes released by reactive dyeing. In addition, reactive and sulphur dyeing processes have been reported to contain the highest quantity of heavy metal, particularly nickel, iron, zinc and chromium. Cadmium was found to be generated only in dyeing.

Also the amount of salt, usually sodium sulphate, required by the dyeing process is very significant.

2.2.6 **Finishing**

A variety of products, depending on the type of finish applied are discharged m the effluent and these include waxes, starch derivatives, and other solids [4, 5, 6].

2.3 Dissolved oxygen

The presence of readily biodegradable compounds in the waste, coming from all the processes discussed above, would impose an oxygen demand that would lower the level of dissolved oxygen in watercourses. This could result in the death of aquatic life because of lack of oxygen, or through the toxic effects of discharged chemicals. The rapid consumption of dissolved oxygen in a stream may be further accentuated by benthic decomposition that may yield methane, hydrogen sulphide and other dissolved gases that, in turn, would cause an additional (biochemical) oxygen demand on the stream. If the suspended solids load is inorganic in nature, it would settle on the bed of stream and would completely sterilise it over time. Thus the stream will not be in a position to sustain aquatic life [7].

However, the oxygen level in a river stream is normally restored naturally either after a certain period of time, or in a flowing waterway, further downstream. The time for the oxygen level to restore itself after the addition of the pollutant is called the recovery time. Recovery time depends largely on the degree of agitation of the water. Greater agitation of the water would result in a larger surface area for air to dissolve in and hence promotes quicker recovery. Therefore, a fast flowing river, which is characteristic of most Mauritian rivers, passing over rocks or waterfalls would restore its level of dissolved oxygen much quicker than a still lake or slow river [8].

Another characteristic of textile effluents is their high temperature in the range of 40° to 80° C. One effect of thermal pollution is that the solubility of oxygen in the water body reduces as the temperature rises. This is detrimental to some forms of aquatic life [9].

2.4 Salinity

In natural waters, salts are chemical compounds comprising of anions such as carbonates, chlorides, sulphates, and nitrates (primarily in ground water), and cations such as potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na).

The various ions/salts used for cotton and wool processing is shown in Table 2.1 below. They are discharged in the final effluent in the range of 90-95 % of the original concentration and is not removed by conventional biological treatment plants.

Table 2.2: Ions/salts used for cotton and wool processing

Salinity: Cotton Processing	**Anions and Cations**
Desizing	sodium and chloride
Scouring	sodium, carbonate & phosphate
Softening	sodium, sulphate, ammonium & chloride
Mercerizing	sodium & carbonate
Bleaching	Sodium, hypochlorite, peroxide & chlorate
Finishing with resins	ammonium, sulphate, magnesium, chloride, **zinc,** nitrate, sodium & carbonate
Dyeing	sodium & chloride

Salinity: Wool Processing	**Anions and Cations**
Scouring	sodium, carbonate, ammonium & phosphate
Softening	sodium & bromide
Bleaching	sodium & peroxide ion
Dyeing	almost all common ions plus sulphite, chromium and copper

Under ambient conditions, these compounds are present in proportions that create a balanced solution. If there are additional inputs of dissolved solids such as inorganic salts to the system, the balance is altered and detrimental effects may be seen [10].

Sodium sulphate and magnesium sulphate levels above 250 mg/l in drinking water may produce a laxative effect. High levels of total dissolved solids, especially the presence of sulphates may impart an objectionable taste to drinking water. Chloride, in particular, has a low taste threshold [IO].

The sulphate concentration significantly affects the usefulness of water in a variety of ways. Salt in intake water, for example, may interfere with the chemical processes within plants. Dissolved salts in the effluent often constitute a great problem through salinity• associated corrosion, scaling in boilers and heat exchangers and by serving as a substrate for organisms implicated in bio-corrosion.

High salinity may interfere with the growth of aquatic vegetation. Salt may decrease the osmotic pressure, causing water to flow out of the plant to achieve equilibrium. The plant can thus, absorb less water and this would cause stunted growth and reduced yields.

Salinity (the concentration of dissolved salts in the water) is an important element of a habitat. Aquatic animals are adapted to living within certain salinity ranges. Chloride concentrations greater than 400 ppm are known to be detrimental to fresh water fish [2].

In Mauritius all the rivers find their way to the sea. Under natural conditions, estuarine water may fluctuate between fresh and brackish, depending on the flow rate of the river discharging into the estuary. Although research has found that estuarine aquatic life is generally tolerant of fluctuating salinity levels, it has been reported that aquatic biota inhabit zones in the estuary according to preferred salinity levels. Thus, if the volume of fresh water entering the estuary fluctuates sufficiently to cause a change in the iso-saline (areas of similar salinity) patterns, species may be displaced and the ecosystem disrupted.

Salt water has a higher density than freshwater and tends to sink and form a dense fil:11 in the cold lower layer. This saline layer, in stagnant waters, does not mix with the remainder of the pond/lake water, leading to decreased dissolved oxygen levels below the surface [2].

2.5 **Toxicity Contributors**

2.5.1 Heavy Metals

Certain components, in particular heavy metals, are toxic and are capable of killing living organisms in water bodies. Moreover, they produce physiological poisoning by becoming attached to the tissues of aquatic organisms and bio-accumu!ate. As a result, their increasing concentrations can build up in food chains. The metals of concern in textile wastewaters are mainly cadmium, chromium, lead, nickel, iron and zinc [1 l]. The problem is aggravated by the fact that aerobic digestion in activated sludge systems does not reduce toxicity substantially [2].

Cadmium is highly toxic and is undetectable in filtered water that is neutral or alkaline. Concentrations of around 0.01 mg/I can retard the growth of aquatic plants and 0.1 mg/! of cadmium can be lethal to both oysters and aquatic plants. Shellfish can accumulate cadmium from bottom sediment. In the presence of other metals like copper and zinc, the toxicity of cadmium goes up. It ought to be noted that its permissible limit in drinking water supplies is 0.0! mg/! [1 l].

There is still a debate as to whether Chromium, Cr(Ill) or Cr(VI), is toxic. But the fact that chromium ions are extensively used in the dyeing of wool with chrome dyes and that either of the ions may be present, by subsequent reduction or oxidation reactions, is a cause for concern. Concentrations of 5 mg/I for Cr (VI) can affect many plant species adversely [2] and drinking permissible limit for the ion is set at 0.05 mg/L.

It has been found that Cr(III) forms a I:2 complex with soluble organic compounds in wastewater treatment plant effluents and that the oxidation of Cr(Ill) to Cr(VI) in the activated sludge process is negligible.

Other ionic species present in effluents such as nitrates and sulphates also pose serious threat to stagnant waters, thereby affecting aquatic life and these have been discussed, elsewhere, in more details [8].

2.5.2 Dyes

In a survey of some 3000 dyes tested by the Ecological and Toxicological Association of the Dyestuffs Manufacturing Industry (ETAD), it was concluded that many dyes are effectively not toxic to fish. Only 2% of the dyes tested were found to be toxic at level of less than 1 rng/L. Another survey carried out by !Cl (1981) showed that approximately 75% of their dyestuffs tested were toxic at the limit dose of 100 mg/L and 3.5% were toxic between 0.1 to 1 mg/L. From various studies, it is clear that for the vast majority of dyes, toxic effects in aquatic environment are not the issue; although some azo dyes can be partially or even significantly biodegraded releasing toxic compounds like aromatic amines [5].

In addition, since our rivers are generally fast flowing it is least probable that strong colours would prevent light penetration that would otherwise affect aquatic life adversely. Dyes are stable chemically and photolytically, which thereby makes them difficult to degrade under aerobic conditions.

2.5.3 Surfactants

Surface-active' agents are used mainly in the processes of desizing, scouring, and mercerising. Ionic types, particularly cationic, are toxic to bacteria. Cationic agents absorb on the negative bacterial surface, breaking their membranes and hence inhibiting their growth after a critical concentration. The inhibitory action of the anionic (active in the acid range) and cationic agents (active in the alkaline range) is influenced greatly by their pH. On the other hand, non-ionic agents do not inhibit bacteria. Surfactants, in general, not only hinder the action of bacteria but also interfere with effective oxygen transfer in biological treatment systems, are difficult to degrade and toxic to aquatic life. Alkylphenol ethoxylate, a surfactant, in activated sludge treatments is resistant to bacteria, thus is not biodegraded but is adsorbed on the sludge and this is the case for more than 80% of the surface active agents [11].

Most of the dispersants, sequestrants, scouring agents and other surfactants are multi-component systems and their formulations are usually not known to the users or even suppliers of these products.

Resin finishes such as Di-Methyl Di-Hydroxy Ethylene Urea (DMDHEU) are non-biodegradable and have very low BOD values as compared to their COD values. These finishes usually require metal catalyst in their applications and residual finishes may be toxic to the environment.

In Mauritius, no full-fledged study of the impact of textile wastewater on the environment has been carried out. In this respect, references to investigations that have been undertaken abroad on this subject have been made in order to understand the situation locally.

The toxicity of textile mill effluents (TMEs) as a whole effluent should be assessed, rather than determining the toxicity of individual constituents, because of the chemical complexity of TMEs and since processes and chemicals used vary from mill to mill and over time as well [12].

In order to interpret any aquatic toxicity data for textile effluent, it is vital to have the wastewater well characterised, otherwise no general conclusion can be drawn on the toxic potential of the effluent. The processes used in individual plants can also change throughout the year according to the outputs required, and many mills employ batch processes resulting in effluents whose toxic and other polluting potentials would change dramatically within temporal scales of weeks to months.

Moreover, the receiving environments should be characterised also, so as to estimate the extent of the impact that will occur with a given discharge. The physical characteristics of aquatic receiving environments must be determined, and the effect on populations and communities of aquatic organisms from treated and untreated TMEs must be measured. The acute and sub-lethal toxicity to aquatic organisms of treated and untreated effluent and sediments near outfalls would have to be completely established. Finally, the chemical use patterns within the textile industry, particularly those associated with dyeing, are changing rapidly as technology evolves. The toxicity database, if any, may have to be revised accordingly.

2.5.4 Results of Toxicity Studies: Canada

In Canada, only one study reported on the effects of TMEs on aquatic life in receiving waters. A statistically significant decrease in abundance and diversity of benthic macroinvertebrates was found at sampling stations in the effluent plume of a knit fabric dyeing and finishing mill discharging untreated effluents to a freshwater river in Nova Scotia. That impact was observed during field studies in both the fall and spring, and was not specific to one group of aquatic organisms.

In another recent study by Environment Canada in 1992 [12], the untreated effluent from three textile mills in the Atlantic Region was chemically characterised and evaluated from an aquatic toxicity standpoint. The ecological impact of untreated effluent discharges on aquatic envirorunents was also determined. Organic chemicals identified in effluent samples generally fell into one of five groups: detergents/surfactants, plasticizers, carriers, mineral oils, and miscellaneous chemicals. The large number of organic compounds identified in the effluents was typical of the number of auxiliary chemicals used in textile dyeing.

The results of toxicity tests showed that with one exception, all samples were acutely toxic to all organisms tested; all samples showed sub-lethal toxic effects, including reproductive and growth impairment, to all species tested; and all samples were mutagenic. A decrease in abundance and diversity of aquatic benthic invertebrates was observed in the area of the effluent plume at one mill that discharges to a freshwater river [12].

Untreated effluents from the three textile mills were tested, and the 96-hour LC50s to rainbow trout ranged from 8.2% to 70.7%. In other words, 50% of the test organisms (rainbow trout) died in untreated effluent samples that had been diluted from 8.2 % to 70.7% of their original concentrations. This clearly shows that due to variations in the range of toxicity for different types of wastes, a large number of tests need to be performed before deciding what should be the standard dilution of textile wastewater.

In Mauritius, an assessment is needed to evaluate the toxicity and biological impact of treated and untreated textile mill effluents on its aquatic ecosystems. The minimum dilution factors for mixed effluents would need to be determined both for untreated and treated effluen'ts before discharge to any receiving body such that they are not toxic to aquatic life found in the Mauritian envirorunent.

Chapter 3

REVIEW OF EFFLUENT TREATMENT TECHNOLOGIES

3.1 Introduction

There is undoubtedly an increasing global awareness of the environmental problems associated with all human activities. The textile industry is constantly under pressure to treat its effluent and/or manage its waste. Some progress has been made in minimising waste production by either pollution prevention strategies or through recycling methods. Where these are not feasible, treatment followed by safe disposal has been adopted as a waste management technique [13].

Very often technologies that allow the treated effluent to be recycled are associated with high capital costs and are therefore not very attractive to textile dyers and finishers [5]. On the other hand, some companies lack the skills to operate recycling or treatment equipment properly. Other companies do not generate large enough quantity of waste for economic operation of recycling equipment. The permitting process required for an on-site waste treatment facility is both time-consuming and expensive. In those cases, off-site recycling or treatment where wastes from multiple facilities are combined can be an excellent waste management approach.

3.2 Effluent Treatment Methods

The various methods of effluent treatment can be classified as pnrnary, secondary or tertiary as shown in Table 3.1. Their nature can be physical, chemical or biological or a combination of two or all. The tertiary treatment can be further divided into three main processes viz., adsorption, oxidation and separation. There are many treatments that come under these three processes. The type and extent of treatment vanes because of the changes and differences in processes, chemicals and concentrations. But the final effluent to be disposed to water bodies has to be of similar quality as governed per limits imposed by local authorities.

Table 3.1 Treatment Methods

Primary	(Biologtcnl)	**Tertiary**
• Screening		• Adsorption
• Equalisation or Flow Balancing	• Activated Sludge	• Coagulation/ Flocculation
• Neutralisation	• Waste Stabilisation Pond	
• Sedimentation	• Trickling Filter	• Membrane Technology
• Flotation	• Anaerobic Digestion	• Chemical Oxidation
		• Bio-adsorbents
		• Super-Sludge

The purpose of primary treatment is to remove floating and heavy particles, or suspended matter from the wastewater physically and to achieve uniform flows and concentrations. The techniques, which include *screening, equalisation, neutralisation and sedimentation,* depend on the physical properties of the impurities such as particle size and specific gravity.

The secondary, treatment step is generally based on biological oxidation whereas tertiary treatment may involve physical, chemical or biological or their various combinations depending on impurities to be removed [14].

3.2.1 Primary Treatments

3.2.1.1 Screening

The first step in the treatment of effluent is screening which remove coarse floating particles or suspended matter. The screens can be classified as coarse and fine [15]. The coarse screens are used to remove pieces of fabric (rags) whereas fine screens remove smaller particles such as fibres and lumps of chemicals. Failure to remove rags, long fibres and other such matters may result in the blockage of pumps and valves. A wide application of screens is found in stone washing departments where pumice stone has to be removed from effluent before further treatment is continued. Screening is usually done as a preliminary treatment prior to any other treatment.

3.2.1.2 Equalisation or Flow Balancing

Flow balancing is the second essential step for effluent treatment that ensures that the hydraulic, chemical and biological load on the treatment plant can be kept fairly constant and temperature variations minimised. This is important because textile effluents vary largely in composition and flow over a period of time, hence the effluent may require equalisation before it is subjected to further treatment.

Equalisation consists of holding the waste for some pre-determined time in a tank that produces an effluent of fairly uniform characteristics, which is released at a constant rate. A certain amount of flow neutralisation and homogenisation is also achieved by means of a mixing system in the tank. The wastewater, on entering the tank, is immediately dispersed throughout and acquires the properties of the content of the tank.

Moreover, mixing of acidic, neutral and alkaline streams reduces the requirement of chemical addition for neutralisation. The tank also provides a means for sufficient dilution to prevent toxic substances from inhibiting biological processes that are secondary to this stage.

In Mauritius, almost all effluents from dyehouses are equalised before disposal into either the sewer or surface waters.

3.2.1.3 Neutralisation

Neutralisation is a chemical process that reduces the acidity or alkalinity of wastewater. Our effluents are mainly alkaline in the pH range of 9-12; therefore they need to be dosed with mineral acids in order to bring down the pH in the range of 5-9, which satisfies the environmental norms, before they could be discharged directly to the sewer. If further treatment such as the activated sludge process, which is pH dependent, is to be carried out it is desirable that the pH is brought down to the range of 6.5-8.5 for optimum operation [2). Neutralisation may be carried out in the flow-balancing tank. Sulphuric acid is the most common mineral acid used in Mauritius. Organic acids like forrnic acid should not be used as they increase the organic load of the effluent.

3.2.1.4 Sedimentation

Effluents are treated by sedimentation to reduce the content of settleable or suspended solids of the wastewater for the next treatment stage. In the sedimentation tank, solid particles settle mainly due to gravity. The settleable solids originate from materials being processed or 'result from processes such as precipitation that is an integral part of treatment techniques. Retention time and flow rate through the sedimentation unit, vary with the nature of the solids and the degree of settlement required [15). Another benefit of this process is that partial equalisation of flow rates and chemical load is achieved.

In Mauritius, sedimentation is carried out after biological treatment but the normal practice is to carry it out both before and after the biological stage.

3.2.1.5 Flotation

Flotation is a physical method to remove suspended solids from wastewater and to concentrate sludge. Thus, flotation offers an alternative to sedimentation, especially when effluent contains oils, fats or grease [16]. This stage is not practised in our effluent treatment plants due to high capital and running costs, particularly of the air compressor, which is used for blowing air into the tank to bring the solids to the surface [5].

3.2.2 Secondary Treatment

3.2.2.1 Biological Treatment

After the primary stage of treating the effluent, a secondary treatment, essentially biological, is necessary for removing soluble or colloidal organic that cannot be removed by the primary treatment [2].

There are several systems of application of biological degradation to wastewater treatment. They are basically aerobic and anaerobic processes that require the use of different microorganisms in either an oxygenated or deoxygenated atmosphere respectively. In case of aerobic treatment, the organic matter in wastewater gets decomposed to give water, carbon dioxide and simple inorganic substances (scheme I), whereas the organic matter gets converted to methane and carbon dioxide gas when the effluent is degraded anaerobically.

The biological treatment plant can remove only biodegradable colloidal or dissolved organic substances and it cannot deal with non-biodegradable minerals and organic substances like CMC, fats. formaldehyde resins and others [11).

3.2.2.2 Aerobic Biological Treatment

There are various ways of degrading effluent aerobically such as activated sludge method (which is the most popular of secondary treatment being given to local textile effluents), waste stabilisation pond and trickling filter [11].

Aerobic decomposition tends to give end products that are nearer to complete oxidation, and for this reason waste treatment processes are generally carried out under aerobic conditions.

A typical biological reaction, which takes place in an aerobic environment, may be simplified in the form of the following equation:

$$\text{Organic Matter} + O_2 + \text{Microbes} \Rightarrow CO_2 + H_2O + \text{Energy} + \text{More Microbes}$$

The rate of organic biodegradation is dependent on various factors such as temperature, pH and the level of nutrients [11]. In general, our wastewater is alkaline, contains insufficient nutrients and contains heavy metals above the consent limits. Therefore, the rate of microbial action may be severely retarded and this would reduce the efficiency of lowering the BOD. On the other hand, sewage mixed with textile wastewater may help in nourishing microbes with nutrients and hence increasing the rate of biodegradation.

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3.2.2.3 Activated Sludge System

The activated sludge process has been widely adopted and further developed giving it a unique flexibility of operation. It is the most common biological treatment that has as its functioning principle the degradation of organic matter, in the presence of air, and its transformation in a floe suspension easy to settle, allowing the use of gravitational liquid-solid separation techniques. This system uses aerobic microorganisms to decompose organic matter in wastewater into water, carbon dioxide, and simple inorganic substances and are themselves converted into microbial cell tissues after growth. Most of the organic matter is removed, but non-biodegradable organic substances like dyestuffs pass through the system unaffected.

It is to be noted that addition of oxygen into the aeration tank is an important means of removing some compounds such as iron, magnesium and carbon dioxide. It also promotes chemical oxidation, eliminates organic compounds that resist biological treatments and oxygenates the effluent before its rejection.

For optimum level of oxidation and synthesis, the following conditions should prevail in the aeration tank [I I]:

- pH range of 6.5 - 8.5
- Dissolved oxygen concentration ofa least l-2 mg/I
- Absence of toxicity
- Food to microorganism ratio (F/M) of0.2 to 0.6.
- Presence of essential nutrients such as phosphorus and nitrogen, with a BOD:N:P ratio of l 00:5: l.

Our survey has revealed that the conditions for optimising the process are not properly monitored and in practice not very much achievable. Therefore, the system usually operates at low efficiencies. But the activated sludge system still offers a number of advantages; one of which is that it is suitable for handling large volumes of wastewater. And it has also a few limitations. The sludge generation is high and it has been found that the aerobic system does not sufficiently remove colour from textile effluents, especially for reactive dyes that pass through the system almost unaffected and enter the receiving water body [5].

3.2.2.4 Waste Stabilisation Pond

It is the least expensive method of biodegradation of organic matter in wastewater, but requires plenty of space. The pond is easy to operate, however the mechanism of the processes, which include aerobic, anaerobic, photosynthesis and sedimentation all taking place simultaneously in different zones of the pond, is very complex [I I].

There is one dyehouse in the north of the island that uses this technology but then again, the aeration system is not functioning properly and hence the treatment of the effluent is not fully optimised.

3.2.2.5 The Trickling Filter

In this aerobic type of treatment, the wastewater is brought into contact with a mixed microbial population in the form of slime attached to the surface of a solid support medium.

The trickling filter or biological-film system has been used for domestic waste, milk processing, paper mills and pharmaceutical wastes. It is easy to operate and can handle peak shock loads and works satisfactorily just after instalment. It can also provide good performance with a minimum of skilled operator attention [17). However, domestic waste is non-toxic, more dilute and uniform in composition, unlike textile waste. Therefore, this method is not popular for treating textile wastes [2, 18).

3.2.2.6 The Anaerobic Digestion System

In anaerobic biodegradation, the organic matter in wastewater is essentially degraded and treated through two steps of biochemical reaction in a closed system in the absence of air. In the fermentation step, the organic matter is degraded into low-grade fatty acids which is further degraded to yield methane gas in the process.

This type of biological degradation is used in treatment of high concentration of fermentable organic material, especially wastes from the meat industry and used as a method of treating sludge prior to its ultimate disposal [19, 20].

Although anaerobic treatment has traditionally only been used to treat the solids fraction of the waste at a sewage treatment works, recent studies abroad have resulted in this process being adapted for the successful high-rate treatment of liquid industrial wastes. Work carried out by ETAD showed that water-soluble azo dyes are degraded anaerobically and the colour of the dyes is removed substantially [5, 21). Since azo dyes account for over 50 % of all textile dyestuffs produced and are the most common chromophore of reactive textile dyes [22], an anaerobic treatment system can be proposed as a viable Option for the decolourisation of textile effluents from reactive dyeing. Laboratory investigations undertaken using a target reactive dye (C.I. Reactive Red 141) show that decolourisation of reactive azo dyes takes place.

But other workers have shown that on a large scale, it is not an efficient process for colour removal. In addition, large concentrations of sodium and sulphides present in the dye effluent in an anaerobic digester can be inhibitory to the methane-producing bacteria (MPB), resulting in digester instability and even failure if toxic levels of sulphide are reached. The sulphide is produced through the reduction of the sulphate in the dye effluent as a result of the action of sulphate reducing bacteria (SRB) present in the anaerobic digester environment.

As compared to its aerobic counterpart the anaerobic digester entails higher capital costs. It cannot deal with toxic compounds. Very few processes used are anaerobic since these conditions produce a variety of incomplete end products that have unpleasant odours and are unsuitable in terms of BOD [5].

The anaerobic treatment has not well established itself as a viable option for treating textile wastewater and, therefore, should remain a secondary choice [5].

3.2.3 Tertiary or Advanced Wastewater Treatment

Advanced wastewater treatments, which may include certain biological processes, are expensive and are used when the wastewater is to be reclaimed or re-used or in order to satisfy any of several specific goals. They include the removal of (a) suspended solids (b) BOD (c) COD (d) dissolved solids (e) toxic substances or/and (f) colour [2].

3.2.3.1 Adsorption Methods

Adsorption is a physical surface phenomenon whereby the dissolved substances in wastewater are attracted to the surface of adsorbent [23]. The various methods are differentiated by the adsorbents used. Some of the currently used adsorbents are:

granulated activated carbon (GAC), powdered activated carbon (PAC), inorganic adsorbents and resins [5, 23, 24, 25].

3.2.3.2 Coagulation/Flocculation

This physico-chemical treatment removes suspended solids that have been carried over from secondary treatment. Physico-chemical processes may precede biological treatment to enhance the effectiveness of the latter or may be used after biological treatment to meet specific discharge limits. In Mauritius, coagulation is always carried out after biological degradation in the aeration tank of activated sludge systems. The coarse particles are removed in primary treatment methods but a variety of colloidal particles remain after biological treatment. Besides fibres, these solids include oil, grease, microscopic organisms and mineral particulate. Coagulation/ flocculation can be used to remove these pollutants [23].

Positive ions such as aluminium ions (Al^{3+}) are used to destabilise negatively charged suspended and colloidal material so that the particles can be clumped together and form large stable floes that easily settle down to form sediment. A rapid mix process is used to mix the coagulant with effluent thus providing a complete dispersion of coagulant. Both suspended & colloidal solids are removed if addition of coagulants and other conditions are properly controlled.

Aluminium sulphate or alum is unsatisfactory for removal of colour generated from azoic, reactive' and basic dyes, but is good for treating disperse, vat and sulphur dyes [26]. Treatment with alum reduces the BOD by about 30-35% by the removal of organic solids. On the other hand, total dissolved solid (TDS) increases by an amount varying between 2-18 % [27].

Polyelectrolytes, which are coagulant aids, are added when the concentration of colloidal matter is very low. Their use greatly enhances the floe forming ability of the primary coagulant, thereby reducing effluent turbidity and also the amount of primary coagulant dose [26]. The advantages and disadvantages of such a system have been discussed elsewhere [2, 5, 17, 26, 28, 29, 30].

Other technologies such as membrane technology (reverse osmosis, nanofiltration or electrodialysis), chemical oxidation technology and microalgae could also be used and a brief description follows.

3.2.3.3 Membrane Technology

Membrane technology is a physical treatment, which involves the separation of soluble and insoluble materials from wastewater stream, and the concentration of these materials into one small waste stream. It relies on the principle that when a liquid passes across or through a physical barrier, particles whose size is larger than the pores in the membrane are retained on one side of the barrier, while the remaining liquid passes through. The characteristics that differentiate it from other forms of filtration are the relative size of the particles being filtered and the driving force (pressure or a chemical concentration gradient) which allows the process to work. The result is a clean product water stream, ready for reuse [29]. The use of membranes for the removal of salts from textile wastewater is a well-proven physical treatment. Full-scale effluent treatment with membrane technology appears to be feasible only as a third or fourth treatment step. The four basic membrane filtration processes, in increasing order of particle size, are reverse osmosis, nanofiltration, ultrafiltration and microfiltration. Nanofiltration, for example, is effective in removing large ions and organic molecules from the effluent whereas treatment using reverse osmosis technique retains most of the inorganic ions of the effluent [5, 31]. None of these technologies are used in Mauritius for both economic and technical reasons.

3.2.3.4 Chemical Oxidation Technology

Chemical oxidation is a process that is used to break down the organic component of the effluent. It could be either a partial oxidation for the removal of colour (destruction of the chromophoric group) or the total oxidation of organic matter, bacteria and viruses to form carbon dioxide and inorganic ions. Various oxidants have been used under different conditions with varying success and these include reagents such as hypochlorite, chlorine dioxide, persulphate, Fenton's reagent in conjunction with peroxide, UV in conjunction with peroxide, hydrogen peroxide alone and ozone in conjunction with UV [26]. Chlorine-based compounds such as chlorine dioxide is effective in decolourising reactive dyes but undesirable products such as organic chlorides may be formed and chlorine-based products may inactivate micro-organisms in activated sludge wastewater treatment systems [2, 5, 30].

3.2.3.5 Bio-adsorbents

Bio-adsorbents are naturally occumng polymers or their synthetic derivatives that are biodegradable. They either adsorb species within them or under operating conditions act as ion-exchangers. The use of chitin in the removal of dye from textile effluent has been extensively studied and is known [5]. Other synthetic cellulose-based bio-adsorbents have been tried out and they have been found to be very useful in removing colour from the effluent.

Research has also been directed towards the use of microalgae for the removal of heavy metals. Algae are well known for their capacity of binding heavy metals to their cell walls. Conventional processes for heavy metal removal are often not effective or not economical and bio-sorption is a promising alternative. The biosorption of lead, cadmium, nickel and zinc by many taxonomically classified microalgae, is being currently studied. For example, the surface of the algae is modified chemically to investigate its effect on bio-sorption while other works are examining the effect of pH and competing metals on the process. Although the bio-sorption process has many advantages compared to conventional techniques, it is not very well established.

3.2.3.6 Digestion With Super-Sludge

Expensive treatments like oxidation, adsorption or fine filtration give rise to the problem of disposal of concentrated waste. In order to avoid the use of such tertiary treatments, research is under way to culture a 'super sludge' with a greater capacity to digest the noxious components in the effluent that are non-degradable. Certain types of bacteria would be needed in the sludge to break down the harmful molecules and it is important to maintain a high proportion of these organisms through a process known as sludge seeding. Another route of conditioning a 'super sludge' would be to expose the microorganisms in activated sludge to a specific type of waste, with the objective of increasing their population, thus producing a species capable of digesting a specific waste type [32].

In order to treat effluents from dyehouses and allow the water to be recovered and re-used, a multiple treatment stage using a combination of technologies would be required.

Because of the complex and variable nature of the effluent, no single technology is adequate and suitable to treat the wastewater efficiently and effectively.

However, most of these combined systems that allow most of the water to be recycled has a high capital cost and/or high running costs. The alternative would be to make use of established and less capital intensive technologies but the net effect would be that the effluent would only be partially treated.

3.2.3.7 Colour Removal

Effluent from the textile finishing industry is generally highly coloured as a result of the unfixed dyes flowing down the drain. Colour in the effluent is a major problem and it requires special attention because of the potential public outcry although it is not so much an eco-toxic problem as it is an aesthetic one. According to Willmott N. et al (33], historically, the discharge of coloured wastewater from textile dyehouses has prompted more complaints to the water companies than any other form of pollution.

The extent of the colour in the effluent is largely dependent on the depth of shade and the type of dye used for a particular substrate. It has been reported that strong colours such as reds may cause considerable public concern when the coloured effluent is discharged into rivers or canals; especially when the human eye can detect reactive dyes at concentration as low as 0.005mg/L in clear river waters (33].

Besides these problems, the complex and variable nature of textile effluent makes successful decolourisation a difficult matter. In addition, some azo dyes such as benzidine-based direct dyes are easily reduced in wastewater to colourless primary organic amines that are more toxic than the original dyes [34]. Other dyes are known to be mutagenic and some are suspected of being carcinogenic (direct and azoic or azo group containing dyes). Fortunately, these harmful dyes have been banned internationally and are therefore not used in local dyehouses.

Although dyes in their integrated form are non-toxic substances but if the river, into which coloured waters are discharged, is stagnant or slow flowing, strong colours would reduce light penetration and this, in turn, would affect the growth of plants and other living organisms [5].

Reactive dyes are the most common class of dye used in our dyehouses. The degree of fixation of these dyes is known to vary between 50-80%. Thus, substantial amount of the dye would be present in the effluent and this would give rise to highly coloured effluent. And this is difficult to treat due to both the water-soluble nature and the amount of the hydrolysed dye produced. Reactive dyes are, therefore, believed to be the most problematic dye with respect to colour removal [5].

By and large, there are two ways to remove colour from effluent [5]. One is to allow the colour to be concentrated onto the sludge (using methods such as chemical coagulation/flocculation, chemical precipitation, ion-exchange resin (resin from sugar-cane bagasse and activated sludge) which can be either disposed of in registered landfills or incinerated. The other way is to destroy the colour altogether by attacking the chromophore of the dyes using chemical degradation, photo-degradation and biodegradation (anaerobic systems) techniques. Some of the other established techniques available for decolourisation of textile wastewater have been described earlier.

But, it is a fact that there is no single method to remove the wide range of dye classes. A typical dye class can be treated, at its best, by one or a limited range of methods. Each method differs in the efficiency of colour removal for a specific dye class. For example, physico-chernical means such as coagulation/flocculation and/or physical means such as filtration and biomass adsorption may remove water-insoluble dyes such as vat dyes from the effluent. Other water-soluble dyes such as direct and basic are readily (while reactive dyes are much less readily) adsorbed onto biological sludge rather than degraded since most azo dyes are resistant to microbial degradation under the aerobic conditions normally found in wastewater treatment plants. In practice, biological freatments are often combined with physico-chernical methods of colour removal.

Research is still being carried out to find appropriate methods of degrading several types of dyes including those of reactive dyes using biotechnology. Bacteria species are isolated to aid degradation of a particular dyestuff or class. It is believed that some reactive azo dyes, under anaerobic conditions, are reduced to colourless compounds by the action of azo-reductase enzymes [33, 35].

In Mauritius, it has been found that conventional biological treatment processes such as the activated sludge system and the aerated pond do not successfully remove colour from the effluent. Dyehouses connected to the sewer rely on the dilution of their discharge by less coloured wastewater from domestic or other sources to reduce colour concentration.

From the economics point of view, colour removal bears an important cost factor since most of the decolourisation techniques are very expensive. The Knitting Industries Federation (KIF) Report on 'Technological Review of Practical Developments in Removal of Colour From Textile Effluent', mentions the cost and capacity of different short-term treatments. For example, the cost of adding various types of chemicals in the UK varies between 28 to 65 pence per cubic metre and the amount of effluent that can be treated in a day is 120 to 2000 cubic meters. This would represent an expenditure of about Rs160,000-400,000 for dyehouses consuming an average of 15,000 cubic meters per month in Mauritius. The capital costs for long-term end-of-pipe colour removal systems vary between Rs 4M and Rs30M and operating costs range from Rs8 to Rs80 per cubic meters. Clearly, the very high capital and running costs have greatly hampered investment in colour removal technologies. Besides, to be viable in this situation, up to 80% of the process water must be recycled and the equipment must be flexible to cope with any changes in dyehouse chemical/dye recipe [36).

Chapter 4

DISPOSAL OF PARTIALLY TREATED AND UNTREATED TEXTILE WASTEWATERS IN MAURITIUS

4.1 Sewers

More than 75% of textile wastewaters are disposed down the sewer together with domestic sewage which consists of liquid wastes originating from places such as urinals, latrines, bathrooms, kitchen-sinks and washbasins from residential, commercial or institutional buildings. The waste is generally extremely foul because of the presence of human excreta and other putrefying matter [37). It may thus contain pathogenic organisms, sufficient nitrogen and phosphorus and be a source of nutrients for microbial activity [38). Table 4.1 gives details of the typical characteristics of domestic sewage.

Table 4.1: Typical characteristics of Domestic Sewage [43]

No.	Characteristics	Strength of Sewage (mg/l)		
		Weak	*Medium*	*Strong*
1	TSS	100	200	350
2	BOD	100	200	400
3	COD	175	300	600
4	TOC	100	200	400
5	Ammonia-N	5	10	20
6	Organic-N	8	20	40
7	PO4-P	7	10	20

Domestic waste, which is non-toxic, more dilute and more uniform in composition than industrial effluent, provides for both dilution and microorganisms to breakdown biodegradable components of the textile wastewater (8, 23]. This has been shown in a pilot scale study carried out at the University of Mauritius. Results of the study have been given and discussed extensively in another chapter.

The wastes produced by the textile industry, as mentioned earlier, are of variable characteristics, volume, and polluting power. As the type of effluent in Mauritius is mainly restricted to reactive dyeing, its combination with sewage should make its treatment more manageable. Textile wastewater, when made free from toxic substances, can be handled more or less like domestic sewage (37].

On the other hand, the demerits of discharging industrial wastewater into public sewers are that it creates economic problems, deteriorates sewer structures, increases maintenance costs, adds problems to sewage treatment, and may increase lagoon pollution since in Mauritius most of the sewers lead to the sea [8, 23].

Chemisolv, a Manchester Applied Technology Company established 12 years ago and specialising in effluent solutions, has produced a range of products that are effective at treatment works. The Spectrosolv range is a blend of special coagulants, which is currently being patented. Spectrosolv is a highly effective chemical that can be dosed directly into the effluent as it is discharged into the sewer. It acts while effluent travels to sewage treatment works and can be integrated into existing on-site systems where solids settle rapidly in the primary stage leaving clear water.

Apart from colour removal from the effluent, pH is lowered and the chemical oxygen demand is significantly reduced. The products deal with all types of dyes and require minimal space. Certain commercially available water treatment polymers are known to have a serious effect on the performance of sewage treatment works, as they inhibit the function of nitrifying bacteria, and therefore impair the plant's ammonia removal capability. But Spectrosolv products have been shown to have no detrimental effect on sewage works.

The typical cost of using this clean-up chemical solution is in the thousands of pounds, compared to millions for traditional plant since no high-cost equipment is involved.

4.2 The Lagoon/Sea

Normally sewage from coastal and inland areas are disposed via submarine outfalls which are designed to use the natural processes of the receiving water to dilute and disperse the wastes so that the discharge can be assimilated by the marine ecosystem without significant adverse environmental effects.

However, lagoon/sea sewage outfalls, if not properly designed, can be major sources of contaminants to coastal sea-ecosystems. This method of disposal has certainly many advantages in terms of economy and ease, but it also raises important concerns about a number of issues such as seafood safety, public health, ecosystem health and preservation.

The ocean offers relatively rapid dilution of many harmful substances, but it also carries particulates bearing trace metals, bacteria, viruses, DDT and other harmful substances. The potential impacts of these substances on urban populations and on coastal ocean ecosystems are largely unknown. What is known, however, is that sea water normally contains a large amount of dissolved matter. And as such, its capacity to absorb sewage solids is not as high as that of fresh inland surface waters. Moreover, sewage solids, when thrown into seawater, chemically react with the dissolved matter of seawater, resulting in the precipitation of some of the sewage solids. These precipitates are undesirable because they are likely to produce offensive hydrogen sulphide gas by reacting with the sulphate rich water of the sea [37]. This problem is fairly obvious in some coastal areas such as Tamarin, Albion and Belle-Mare.

Also, the specific gravity of seawater is greater than that of sewage, and temperature of seawater is lower than that of sewage, the lighter and the warmer sewage would rise up to the surface when thrown into the sea. This would result in the spreading of the sewage, into a thin film, at the top surface of the sea [37, 38, 39].

Elsewhere, it has been reported that bathers have experienced enteritis or skin trouble due to the presence of sewage near coastlines. This was linked to the fact that the outfalls were not placed at suitable locations where the effluent would not return to bathing beaches by prevailing currents. Moreover, there have been cases of people contracting typhoid after eating contaminated marine molluscs such as shellfish. In Poland, though the aquatic life of bays and river mouths has not been destroyed, some fish have been poisoned and the migration of others has been hampered. Disposal of large volumes of sewage into European coast waters from various countries either close or further away from the shore over the past fifty years or so has been taking place and has affected aquatic life especially closer to the coastlines [40].

The main effects of sewage pollution would be in the coral reef ecosystems that are very sensitive to changes in environmental parameters. There are many locations world-wide where coral mortality and reef damage have been recorded such as the Great Barrier Reef in Australia, Jamaica, Biscayne Bay in Florida, Oahu in Waianae, Gulf of Aqaba and others, due to effects such as nutrient enrichment, sedimentation and toxicity [38].

There has also been concern about the question of pollution of the deep sea by sewage even after dilution and diffusion with seawater. A study was launched by the USC Sea Grant Program that had sponsored investigations of ocean processes and biology associated with the White's Point sewage outfall; the largest sewage outfall in the United States. It discharges an average of 330 million gallons per day into the Palos Verdes shelf adjacent to Santa Monica Bay. For several years, in several interdisciplinary research projects, Sea Grant scientists have investigated the complex oceanographic processes affecting dispersion of the outfall plume and the re-suspension of trace metals and nutrient fluxes from bottom sediments near the outfall. But, according to results obtained so far, it has been shown that the effluent does not have any negative impact and, in fact, may have beneficial effects on primary nutrients and productivity in coastal waters [41].

Another study was carried out in the Richards Bay offshore outfall region, on the KwaZulu-Natal coast in South Africa twice every year, for a period of fourteen years. It was found that there was no adverse impact on health, spawning and the number of fishes, on benthic macrofauna, and on the chemistry of water, sediment and biological tissues. The effluent analysed were grab samples, and were taken from 56 stations in the sea in an area of 2.8 by 2.4 kilometres. Before investigating the impact of the effluents on the marine environment in 1984, the latter was studied in order to compare the results of the study with the environment before there were any discharges of effluent. It should be emphasised that the effluent discharged into the sea, four and five kilometres from the shoreline, from two pipelines is raw and the volume from one pipe was reported to be

110,000 cubic meters per day. This represents a much larger figure than the amount that is discharged into our lagoons through the sewer.

In Mauritius, studies were carried out by a consultant group and were based on the simulations of effluent discharge out into the sea, at about 200 metres from the shore. The results revealed poor dispersion characteristics of the effluent and it is believed that the waste would accumulate at the shore ('shore hugging'). It would, then, undergo anaerobic decomposition and cause repulsive smell. This would represent a health hazard to the inhabitants of the area. Due to chemical and other pollution in some areas in Mauritius such as Port-Louis, Baie du Tombeau and Balaclava, the ecosystems in these regions have been greatly affected [38].

But there is a strong belief that the possibility of discharging effluents, preferably in a partially treated form, into our waters exists. However, thorough studies have to be carried out to determine, amongst other parameters, the current status of the sea fauna and flora and the possible effects of effluent discharge on the ecosystems. More in-depth studies need to be made on the dispersion characteristics of the effluent in both shallow and deep waters and the flow of currents and tides at different places around the island, to determine the feasibility of the project.

4.3 Agriculture

Effluents fron;i dyehouses are very saline in nature due to the large amount of salts used in the different textile finishing processes. It has also been found that even biologically treated effluent contains large concentration of anions and cations.

Research has found that the effect of saline wastewater in agriculture depends on the type of salts, plant and soil, and the method of irrigation. Plants grown in sandy, porous soils tolerate higher water salinity than those in dense soils where drainage is poor. Interestingly, it is known that very low saline waters can slightly increase yields, but irrigation waters containing more than 2000 ppm of dissolved salts could cause appreciable decrease in crop yield. As far as the method of watering the plants is concerned, drip irrigation is recommended. [41). Direct wetting of leavps with saline irrigation water usually causes leaf injury, and for this reason irrigation is applied under the canopy in orchards. Chloride causes specific damage in some crops mainly in perennial fruit trees and ornamentals. Avocado is very sensitive and may be injured by very low levels of chloride due to nutritional imbalance [8)

Salt in the soil may harm crops. Certain salt constituents alone can prove toxic to some plant varieties. Also, high salt concentrations in the soil around plant roots may cause plant dehydration by reversing osmotic conditions (water will flow out of the plant in an attempt to achieve equilibrium). In some cases, rather than destroying a crop, elevated salt levels may simply reduce crop yields and leave the plants prone to disease. The danger of using untreated or partially treated textile in combination with sewage effluent, lies in the contamination of soil and ground water with salt, phosphorus, nitrate and heavy metals. The permeability and soil stability may change in the long run. At present, studies are being done on the use and effect of sewage effluent on tree plantations, urban parks and gardens.

Minor elements like manganese, zinc, iron, boron, copper, and so on are present in the soil and plants in amounts less than 1 ppm in solution and are required for normal growth. Toxic metals such as chromium, lead and nickel, if present in trace amounts, do not represent a threat to the land and crops. Salts comprising of anions such as sulphate, chloride and nitrate and cations like sodium and magnesium each has its own range of concentration that can be applied, depending on the type of soil and plant. Vegetables and tobacco, for example are more sensitive or vulnerable because of the spongy nature of their leaves. Therefore, lower limits would be tolerated whereas fruit crops, whose leaves are covered with wax, can withstand higher salinity limits. Biodegradable chemicals do not affect soil and plants but dyes contain metals and these would need to be analysed to find out whether the metals are within the salinity limits.

Sodium is a hazard to the soil above its consent limits, and it may cause poor aeration and inadequate water supply to the plants. When its concentration is high, the physical conditions of the soil may change through clay particle swelling and dispersion. This, in turn, would cause a reduction in the soil porosity, hydraulic permeability and infiltration rate, and the destruction of the soil structure. A high sodium concentration can be tolerated if the soil solution contains at least I rnol/rn' of calcium, which is normally the case in saline soils. Sodium may affect the potassium nutrition of plants, since at high concentrations sodium ions may compete with the uptake of potassium ions. Nickel, lead and zinc are heavy metals detected in both untreated and treated textile wastewater in varying amounts. The upper acceptable limits of these metals in irrigation water are also known for both long and short-term use.

In Mauritius, at one time, the partially treated effluent from a textile factory was being used for irrigation of sugar cane plantation and it became important to determine its effect on the crop. Unfortunately, no information was available on this matter since studies on the potential use of saline dye effluents in agriculture have not yet been undertaken locally. However, projects on the potential usage of sewage sludge in agriculture would be taken up soon and results are expected in about three to four years' time [8].

Chapter 5

ACTIVITIES OF DYEHOUSES

5.1 Introduction

More than 85 % of all dyehouses in Mauritius are part of companies that are vertically integrated and are operating mainly in the knitting sector. There are only four stand-alone dyehouses functioning as subcontractors. In addition the wet processing sector in Mauritius comprises of two washing plants that are part of two major groups of textile companies.

Table 5.1 below gives an indication of the present employment situation in dyehouses .

Table 5.1: Employment in Dyehouses

Number of employees	% of dyehouses
Less than 60	31
60 - 119	35
120– 179	23
180 - 239	7
240 - 300	4

5.2 Methodology

A survey covering all operating dyehouses in Mauritius was carried out in 1998 to obtain precise information on their activities. A copy of the survey forrn is included in Appendix. The results of the survey are given in Tables 5.2 to 5.12.

5.3 **Material Processed/Month**

By far the most important material processed in dyehouses is cotton. In fact processing of cotton in the form of fibre, yarn or fabric constitutes more than 90% of the activities of dyehouses in Mauritius. Table 5.2 below shows the actual amount of different materials that are processed monthly in tons.

Table 5.2: Materials Processed Monthly

Material	Form	Amount
Cotton	Yarn	400
	Fabric	4000
	Garment	200
Wool	Fibre	250
	Fabric	15
	Garment	170
Polyester/Cotton	Fabric	25
	Yarn	5
	Garment	15
Total		**5080**

Most of the textile materials are dyed in the form of fabric as shown in the Table 5.3 below that gives figures in tons of material processes per month.

Table 5.3: Types of Material Processed Monthly

Material Types	Tons
Fabric	4040
Yam	405
Fibre	250
Garment	385
Total	*5080*

Table 5.4 below gives the distribution of dyehouses as regards to the amount of material processed in tons per month. Most of the dyehouses can be categorised as small-size with about 10% in the medium-size scale.

Table 5.4: Capacity of Dyehouses

Amount Processed	% of Dyehouses
Less than 100	48
100 - 199	35
200 - 299	7
Above 300	10

5.4 Fabric Dyeing

Almost 80% of processing activities of all dyehouses concern dyeing of fabric. Except for only 3 dyehouses that process woven fabrics, the rest are concerned with knitted fabrics. Table 5.5 shows the distribution of dyehouses in terms of fabric dyed in tons per month.

Table 5.5: Capacity of Dyehouses for Fabric Dyeing

Amount of Fabric Dyed	% of Dyehouses
Less than 100	41
100 – 200	47
200 - 300	6
More than 300	6

Winch and Jet dyeing machines, based on the exhaust dyeing method, are the most popular dyeing machines for knitted fabrics. Table 5.6 indicates the number and type of fabric dyeing machines currently in operation.

Table 5.6: Type and Capacity of Fabric Dyeing Machines

Machine	Number		Capacity (kg)	Liquor Ratio
	Manual	Semi-Automatic/ Automatic		
Winch	57	1	200 - 500	10 - 15
Jet	[illegible]	97	45 – 700	6 - 15

The year of manufacture of most of the Winch and Jet machines is 1988 to 1998.

In addition three dyehouses have a total of nine airflow machines with capacity ranging from 200 to 700 kg and operating with a liquor ratio varying between 1:4 and 1:5. Most of these machines are semi- or fully computerised and the year of manufacture is 1993 to 1998.

J

5.5 Yarn Dyeing

Yarn dyeing represents only about 8% of the total amount of dyed and finished textiles. Table 5.7 gives the distribution of dyehouses for dyed yarn in tons per month

Table 5.7: Capacity of Dyehouscs for Yarn Dyeing

Amount of Yarn Dyed	% of Dyehouses
Less than 40	42
40 – 79	17
80 – 119	25
120 – 159	8
More than 159	8

For discontinuous yarn dyeing process currently 51 machines of capacity ranging from 30 to 800 kg are in operation with liquor ratio varying from 1:8 to 1:30. Furthermore 85% of the yarn dyeing machines was manufactured before 1989 and the remaining 15% were manufactured during the period 1995 to 1998.

In addition 5 continuous warp-dyeing machines are operating for the 2 denim manufacturers. All these 5 machines are semi-computerised and the year of manufacture is 1980 to 1998.

5.6 Garment Washing and Dyeing

Garment dyeing and washing represents slightly more than 7.5% of the total textiles processed in dyehouses including wash plants. The actual quantity in tons per month is about 385. However only a very small amount, about 55 tons per month only, is actually dyed. The rest is washed in dyehouses as well as wash plants.

The two main wash plants in Mauritius operate mostly non-computerised machines, all of them with high liquor ratio ranging from 1:24 to 1:30.

There are four dyehouses having a total of 24 garment dyeing machines of capacity varying from 10 to 450 kg and liquor ratio 1: 10 to 1: 30.

5.7 Fibre Dyeing

Only four dyehouses carry out fibre dyeing, essentially wool fibre and a small amount of polyester. About 250 tons of wool fibre and a minute amount of polyester fibre, less than 2 tons, are dyed per month. That represents about 5% of the total amount of textiles dyed.

Currently a total of 15 fibre-dyeing machines are in operation, in addition to the four machines that can process both yarn and fibre. The machines have capacities that range from 5 to 400 kg with liquor ratio of 1: 10 to 1:20. Most of the machines are between 10 to 20 years old, while 80% of them are semi-computerised.

5.8 Water Consumption

The total water consumed in dyehouses including wash plants is about 400000 m^3 per month. Table 5.8 gives the distribution of dyehouses in terms of water consumption in thousand m^3 per month.

Table 5.8: Water Consumption in Dychouscs

Water Consumed (10° m')	% of Dychouscs
Less than 5	31
5–9	17
10– 14	24
15 - 19	3.5
20–24	7
25 - 29	3.5
30 - 34	0
35 - 39	0
40–44	3.5
45 - 49	10.5

5.9 Dyestuff Consumption

Table 5.9 gives the type and amount of dyes used in dyehouses in Mauritius. Reactive dyes, Sulphur Black as well as Vat dyes are the main types consumed. Others in Table 5.9 include basic, disperse and cationic dyestuff

Table 5.9: Dyestuff Consumption

Type of Dye	Consumption in Kg/Month	% of Total Consumption
Reactive	41000	55.5
Sulphur Black	12000	162
Vat	11500	15.5
Direct	9000	12.2
Others	500	0.7
Total	*74000*	*J00*

Almost all dyehouses in Mauritius make use of reactive dyes. Table 5.10 indicates the distribution of dyehouses as regards quantity of reactive dyes consumed in tons per month.

Table 5.10: Consumption of Reactive Dyes

Quantity of Reactive Dyes	% of Dyehouses
Less than 2	64
2 - 3.9	24
4–5.9	4
6– 7.9	0
8 – 9.9	8

5.10 Consumption of Chemicals

The various dyehouses and wash plants in Mauritius consume about 710 tons of different types of chemicals every month. Table 5.11 shows the different types of chemicals and the quantities used in tons per month.

Table 5.11: Consumption of Chemicals

Type of Chemical	Quantity Consumed	% of Total Consumption
Salt	496	69.8
Alkali	100	14.1
Acid	63	8.9
Surfactants	22	3.1
Wetting Agents	20	2.8
Sequestering Agents	9	1.3
Total	*710*	*100*

Salt constitutes the bulk of the all the chemicals that are used. Table 5.12 shows the distribution of dyehouses and amount of salt consumed monthly in tons.

Table 5.12: Consumption of Salt

Quantity of Salt	% of Dyehouses
Less than 15	47.6
15 - 29	14.3
30 - 44	14.3
45 - 59	19
60 - 74	0
75 and above	4.8

Chapter 6

CHARACTERISTICS OF DYEHOUSE EFFLUENT IN MAURITIUS

6.1 Introduction

Effluent from dyehouses has been characterized in terms of the important parameters related to the environment like BOD, COD and heavy metal content. The data have been collected over long enough period of time to account for short term as well as seasonal variations. The study concerned IO dyehouses processing mainly co non and wool and including l wash plant.

6.2 Methodology

Samples of dyehouse effluent were collected over the period August 1997 to August 1999 to assess the characteristics of the effluent from IO dyehouses including I wash plant .The following sampling plan was adopted to take care short-term and long-term variations in the effluent:

- 4 samples collected per day direct from dyehouses outlets .
- Sampling per week: 2

Various tests were then conducted on the samples to measure parameter like BOD, COD and heavy metals' content.

6.3 Results and Discussion

Table 6.1 shows the characteristics of raw textile effluent for the processing of different fibres. Both the range and average values of each parameter are given.

Table 6.1

Fibre type		100% Cotton Knits		Cotton and Wool		100% Cotton Woven		Garment Washing	
No. of Dyehouses Sampled		Five		Two		Two		One	
Type of. Effluent		Raw							
Parameters	Units	Range of (RV) and Average Values (AV)""							
		RV	*AV*	*RV*	*AV*	*RV*	*AV*	*RV*	*AV*
BOD	rng/L	90-620	230	170-750	290	80-3800	750	200-430	285
COD	rng/L	200-1800	550	330-1200	600	250-6300	1600	400-1200	750
TSS	g/L	0.02-0.70	0.20	0.02-1.95	0.20	0.03-0.45	0.13	0.40-1.90	1.10
pH	-	7.1-12.2	9.7	4.6-12.2	9.2	5-12.5	9.0	6.2-12.0	8.5
TDS	g/L	0.1-8.5	3.2	0.3-10.0	[illegible]	0.2-9.0	2.8	0.2-1.3	0.6
Conductivity	mg/L	0.3-17.0	6.2	0.5-20.0	63	0.6-18.0	4.9	0.4-2.6	1.1
Cadmium	µg/L	0.4-120	50	0.6-24	10	0.1	0.0	0.1	0.0
Chromium	µg/L	0.2-100	20	0.5-700	170	0.6-270	140	58-105	60
Zinc	µg/L	80-1500	700	50-600	400	60-700	350	110-140	130
Nickel	µg/L	10-320	90	50-300	220	-	100	95-115	110
Iron	µg/L	0.8-2200	600	30-800	350	50-600	260	400-2100	1300
Temperature	°C	30-57	46	41-51	43	30-51	45	40-50	45

From Table 6.1, it is found that, for all the different fibre processing under study, the COD values are much higher than the corresponding BOD values. This is explained by the fact that textile wet processing is a highly chemical intensive process.

Effluent generated from the processing of 100% cotton woven fabrics is high in both BOD and COD and this is illustrated in Figure 6.1. High BOD values may stem from the fact that enzyme desizing, for the degradation of starch-based sizes, is a common practice for cotton woven processing.

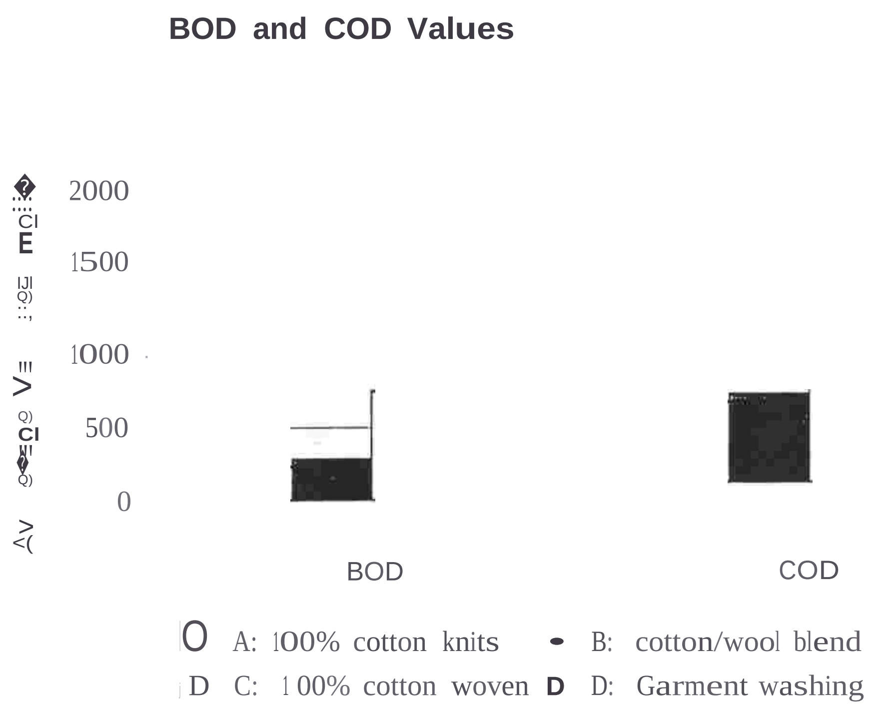

Figure 6.1

Garment washing gives values of COD in the range of 400-1200 mg/L, which is on the high side and this can be attributed to the increasing use of enzymes for the bio-stoning of denims and other fabrics.

From the data given in Table 6.1, it is found that processing of the above fibre types generate a number of heavy metals of widely varying concentrations, as highlighted in

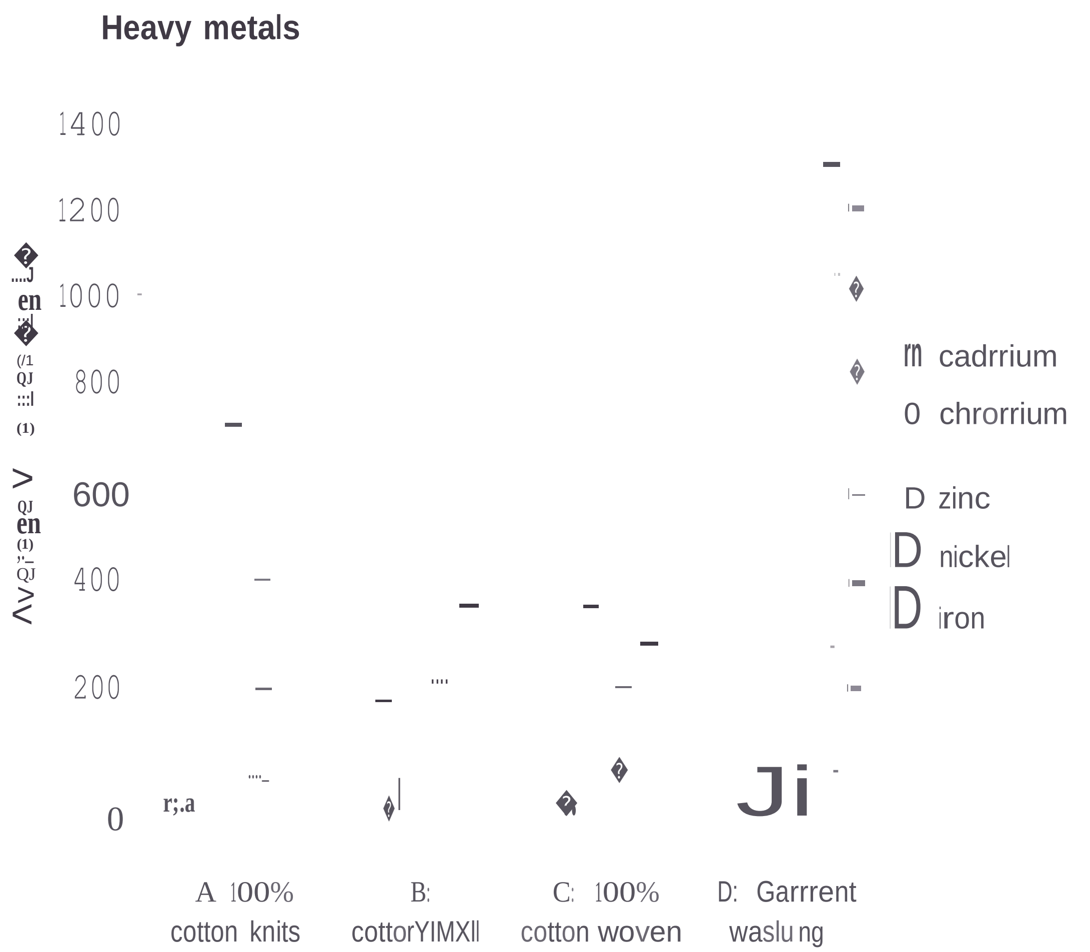

Figure 6.2

The processing of cotton knits reveals unacceptable levels of cadmium, zinc and iron whereas raw effluent from cotton/wool processing carries dangerous levels of chromium and nickel. Woven cotton fabric processing wastewater, on the other hand, contains a high quantity of chromium. Garment washing produces substantial amount of iron in the effluent.

Effluent that is discharged through the sewerage network might, therefore, constitute a potential threat to receiving waters such as the sea.

Effluent from cotton knits and wool processing contain high amounts of dissolved solids whereas the level of TDS from garment washing is acceptable and does not represent a major threat to the environment when discharged into the sea via the sewer.

About 88% of wastewater from cotton knits processing is also discharged into the sea, via the sewer and this could jeopardise localised marine life.

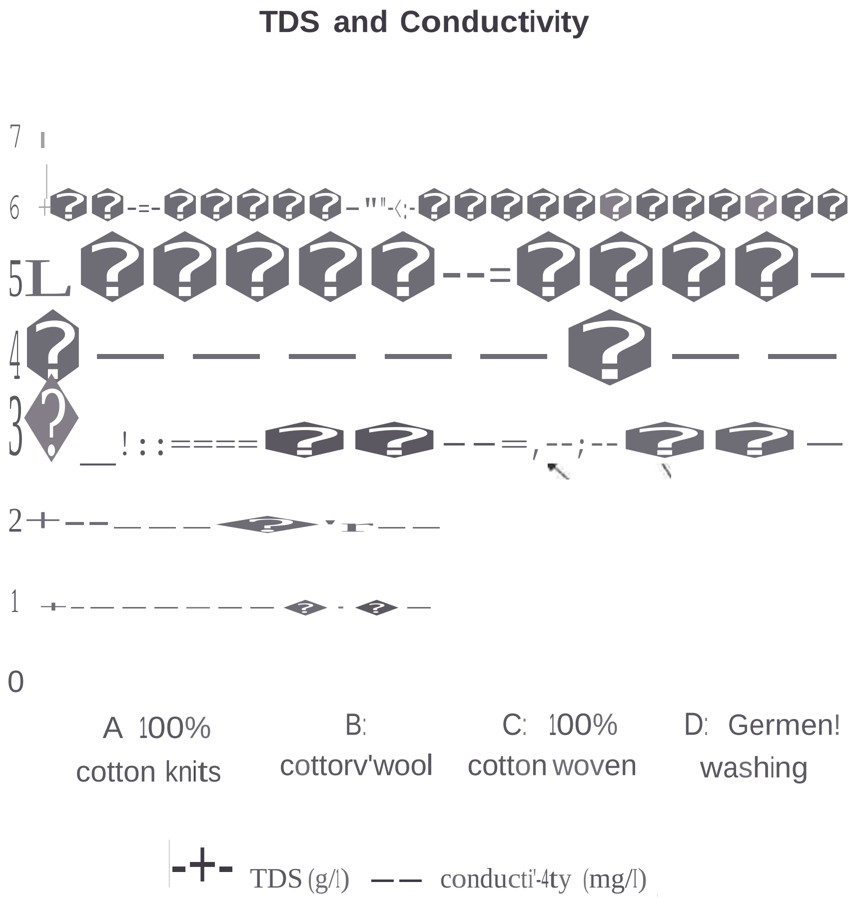

Figure 6.3

As for the remaining parameters, it is observed that cotton garment washing is the largest generator of TSS with an average value of 1.1 g/L. However, it is not a

potential threat to the environment, as would be seen later, since the value is well below the acceptable norms of 2g/L for sewer discharge.

The average pH value, on the other hand, is invariably alkaline in all cases and varies between 8.5 and 9.7 while the average temperature of the effluent varies between 43° and 50 °C.

6.3.1 Raw Effluent Characteristics From Polyester and Polyester/Cotton Processing

The data in Table 6.2 represent the characteristics of raw effluent obtained from the processing of polyester yarn dyeing at high temperature, i.e. without the use of carriers and the dyeing and finishing polyester/cotton yarn.

Table 6.2

Raw Effluent Characteristics of One Dyehouse Situated in Port-Louis and Discharging Into the Stream

Parameters	Units	Min	Max	Average	Consent Limits
BOD	mg/L	87	378	195	20
COD	mg/L	300	976	627	30
TSS	mg/L	20	90	49	10
pH		6.35	9.47	8.2	6.5-9
TDS	g/L	0.38	1.47	0.69	1
Conductivity	mg/L	0.76	2.96	1.35	#
Zinc	ug/L	90	510	321	59
Iron	ug/L	20	210	141	100
Manganese	ug/L	10	30	16	#
Sodium	mg/L	113	537	199	230

It is observed that only the pH, TDS values and the concentration of sodium ions are within the norms. The combining of acidic effluent generated from polyester dyeing with alkaline effluent from cotton dyeing gives effective pH neutralisation and this is reflected in the average pH value of 8.2.

All the other parameters are above the norms and it means that there is a necessity to provide treatment to the effluent from polyester and polyester blends processing before its discharge into nearby streams.

6.3.2 Raw Effluent Characteristics: Districtwise

Table 6.3 shows the characteristics of raw textile effluent from the point of view of the district in which the different dyehouses surveyed are located.

Table 6.3

Districts :		Pamplemousses		Riv. Du Rempart		Plaine Wilhems		Moka		Port-Louis	
No. of dyehouses :		Three		One		Four		One		One	
Type of effluent:		Raw									
Parameters	Units	Range of (RV) and Average Values (AV)									
		RV	AV	RV	AV	RV	AV	RV	AV	RV	AV
BOD	mg/l	80–820	270	160–420	260	90–3820	470	150-620	**330**	87-378	200
COD	mg/l	250–2230	810	380–1320	790	200–6300	920	320-1800	970	300-976	620
TSS	g/l	0.02–1.95	0.20	0.12–0.35	0.23	0.06–0.7	0.12	0.09-0.6	0.28	0.02-0.9	0.05
pH	-	4.6–12.5	9.8	7.6–11	9.4	6.8–12.2	8.9	8-11.5	10.3	6.35-9.47	8.2
TDS	g/l	0.1–10	3.2	1.1–5.1	3.7	0.2–7.6	2.2	1.0-3.7	2.4	0.38-1.47	0.69
Conductivity	mg/l	0.3–20	6.3	2.2–10.2	7.3	0.6–15	3.9	2.2-7.5	4.8	0.76-2.96	1.35
Cadmium	µg/l	0.4–50	20	0.5–100	50	13–120	40	15-110	50	-	-
Chromium	µg/l	0.5–300	140	0.9–100	20	0.3–700	50	0.1–28	07	-	-
Zinc	µg/l	50–1200	60	80–1250	620	200–1500	500	200-700	470	90-510	320
Nickel	µg/l	10–300	150	10–180	60	40–320	150	10-200	100	-	-
Iron	µg/l	30–2100	600	200–1550	650	0.8–2200	300	250-800	470	20-210	140
Temperature	°C	40–55	48	44–57	50	30–51	43	40-55	47	-	-

Figure 6.4 shows the average BOD and COD values pertaining to untreated effluent generated in five districts. The BOD varies in the range of 200-450 mg/l and COD in the range 600-1000 mg/l.

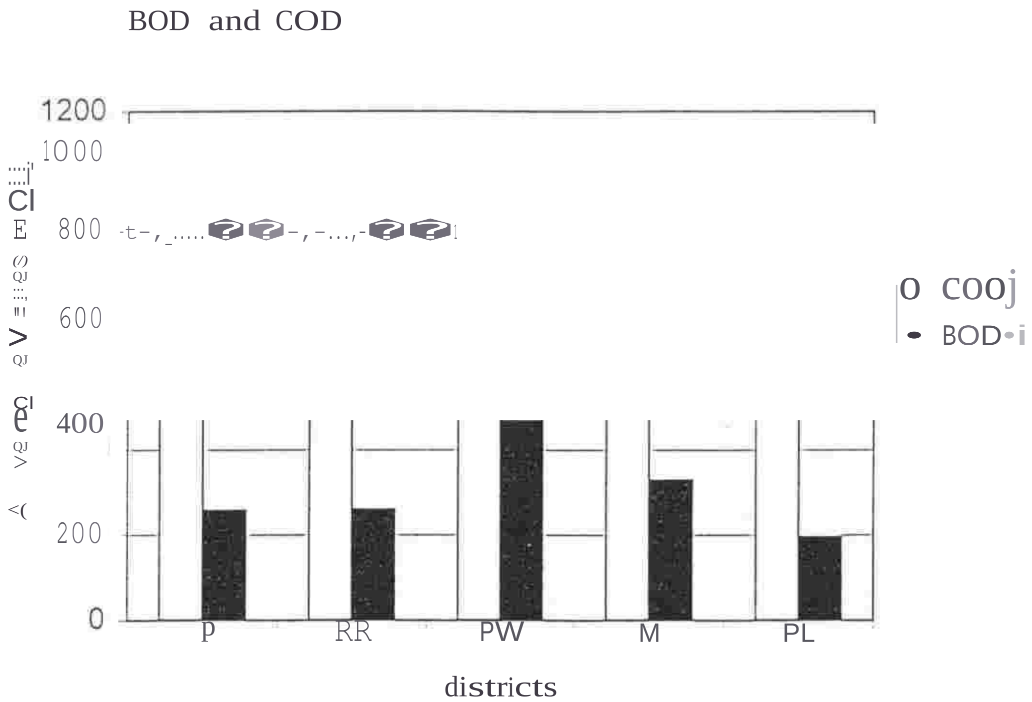

Figure 6.4

'P' ..... Pamplemousses
'PL' .. Port-Louis
'M' ..... Maka
'RR' Riv. Du Rempart
'PW' Plaine Wilhems

Heavy metals

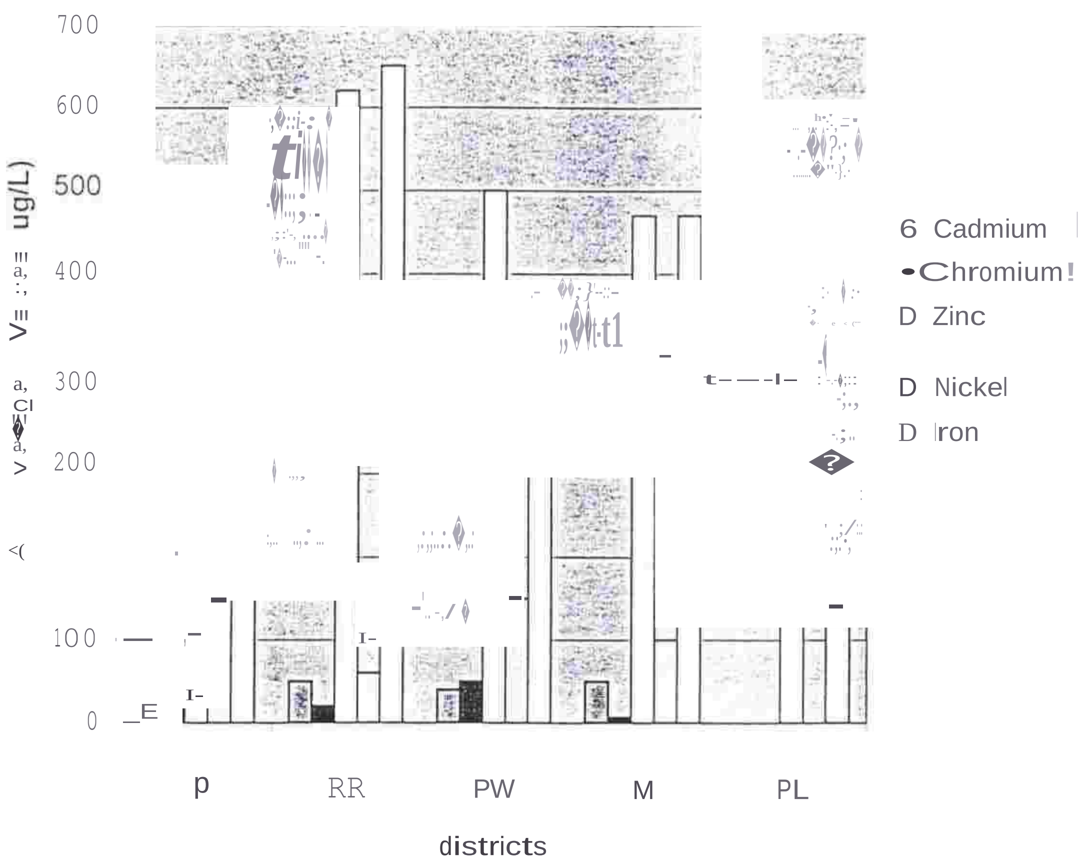

Figure 6.5

The three dyehouses in Pamplemousses and the one in Riviere du Rempart district generate high concentration of heavy metals, in particular cadmium, nickel and chromium. Dyehouses situated in all districts have cadmium, zinc and iron in their effluents in relatively large concentrations. Except for the district of Pamplemousses and Plaine Wilhems, nickel is not a threat elsewhere.

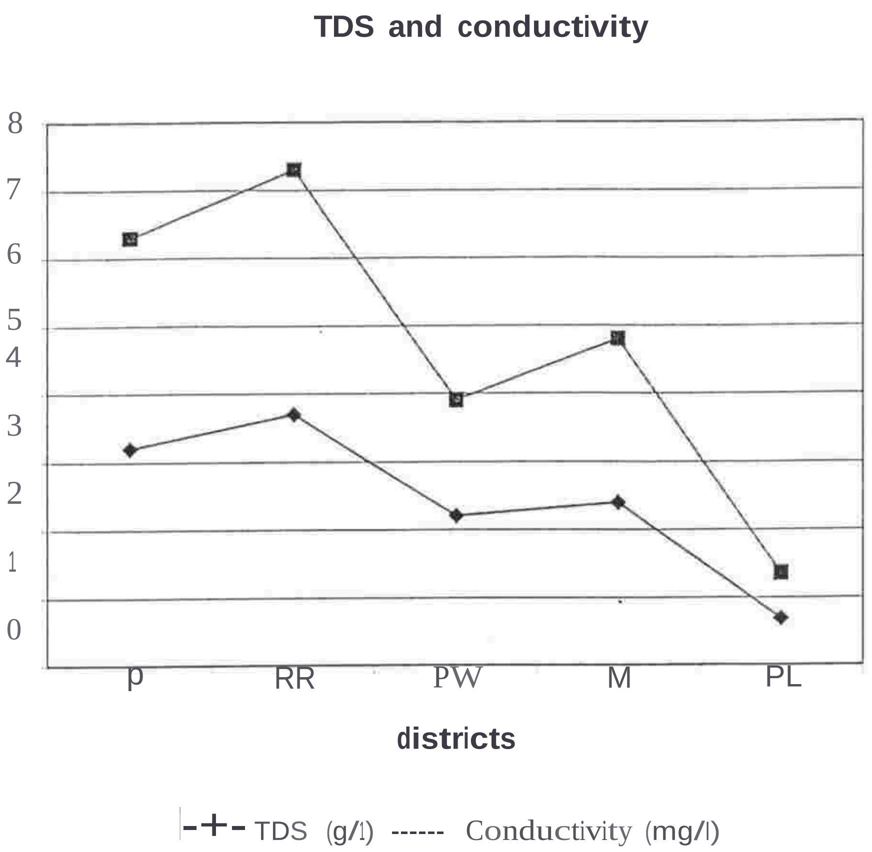

Figure 6.6

Effluents from dyehouses in all the districts, except Port-Louis, contain exceedingly high amount of dissolved solids in their effluents.

It is important to point out that the lagoons bordering these districts (except Plaine Wilhems) may be suffering slow, irreversible damage from untreated wastewaters coming from the sewer lines.

6.3.3 Pollution Loads at Various Discharge Points

Table 6.4 and 6.5 give the range of and average values of both treated (where applicable) and untreated effluent for various discharge points.

Table 6.4

Discharge Points		*Aquifer*				*Sewer*		
No. of Dyehouses :		Two				Five		
Type of Effluent :		*Raw*	*Treared*	*Treated*	*c.l*	*Raw*	*Raw*	*c.l*
Parameters	Units	RV	RV	AV		RV	AV	
BOD	mg/L	160-750	70-295	150	10	90-3820	410	#
COD	mg/L	330-1320	210-840	370	30	200-6300	870	1000
TSS	g/L	0.02-1.95	0.02-1.9	0.17	0.015	0.02-0.7	0.14	2
pH	-	4.6-12.2	7.4-11.5	8.7	5-9	6.8-12.2	9.1	5-9
TDS	g/L	0.3-10	0.5-7	1.4	1	0.1-8.5	2.3	#
Conductivity	mg/L	0.5-20	1.1-13.1	5.5	#	0.3-17	4.3	#
Cadmium	ug/L	0.1-100	0.9-70	25	20	10-120	40	20
Chromium	µg/L	0.2-300	0.1-400	100	50	0.8-700	80	100
Zinc	µg/l	50-1250	70-900	390	500	200-1500	700	30.000
Nickel	µg/L	10-300	10-460	200	100	10-320	110	10,000
Iron	µg/L	30-1550	30-3500	670	#	0.3-2200	500	#
Temperature	°C	43-57	27-42	34	30	30-55	44	40

Table 6.5

Discharge Point		*Surface water*				*Irrigation*			
No. of Dyehouses :		Two				One			
Type of Effluent:		*Raw*	*Treated*	*Treated*	*c.l.*	*Raw*	*Treated*	*Treated*	*c.l.*
Parameters	Units	RV	RV	AV		RV	RV	AV	
BOD	rng/L	80-820	10-190	90	10	150-620	30-140	70	30
COD	mg/L	300-2230	50-850	390	30	320-1800	80-230	180	100
TSS	g/L	0.02-0.45	0.01–0.2	0.05	0.01	0.09-0.6	0.05-0.16	0.1	0.045
pH	-	5.0-12.5	4.2-12.0	7.0	6.5-9.0	8.0-11.5	7.6-9.8	8.5	5.0-9.0
TDS	g/L	0.3-9.0	0.5-4.8	6.9	1	1.0-3.7	2.9-3.6	3.2	2
Conductivity	rng/L	0.7-18.0	1.0-9.5	3.5	#	2.2-7.5	5.8-7.1	6.4	#
Cadmium	etg/L	-	-	-	0.7	15–110	0.7–110	50	20
Chrornium	etg/L	2.5-350	0.6-230	190	2	0.5 -28	0.3 -44	17	50
Zinc	etg/l	60-700	40-590	350	59	100	250 -450	370	5000
Nickel	µg/L	-	-	-	87.6	-	90- 200	170	500
Iron	µg/L	20-600	30-560	270	1000	250-800	300 -700	500	#
Temperature	UC	40-55	28-36	32	30	40-55	34-36	35	30

It is good to note that, in all cases, the sewer receives untreated effluent and that effluent going into aquifers, surface waters and for irrigation are all treated.

c.l— consent limit
'#' – denotes consent limit not available
'-' – denotes test not performed for particular parameter

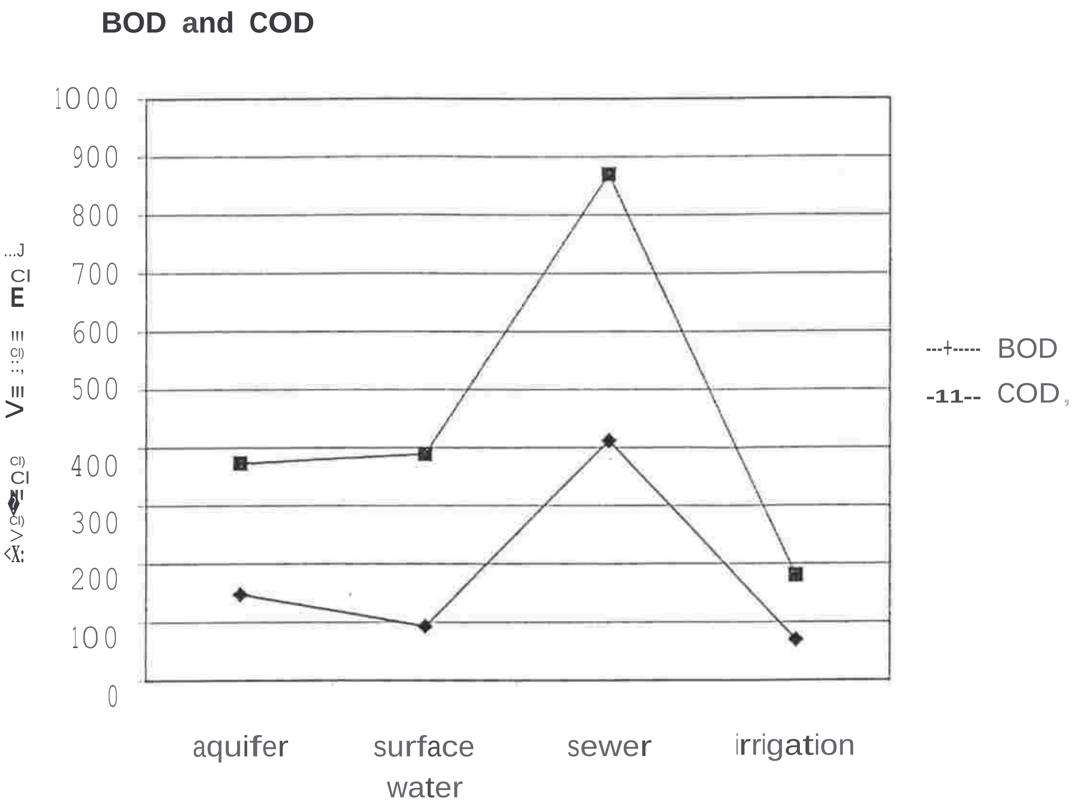

Figure 6.7

For discharge points such as aquifer, surface water and irrigation purposes, the organic loading after treatment is well above the limits prescribed by the Ministry of Environment.

However, BOD and COD values, which are 410 mg/L and 870 mg/L respectively, are not a serious problem when the untreated effluent is discharged in the sewer. This has been confirmed through experiments, which have been described in other chapters, carried out at the University. Both BOD and COD values, when mixed with raw sewage have been found to decrease rapidly with time to a very large extent and in any case the average values are well below the consent limit for sewer discharge.

Heavy metals

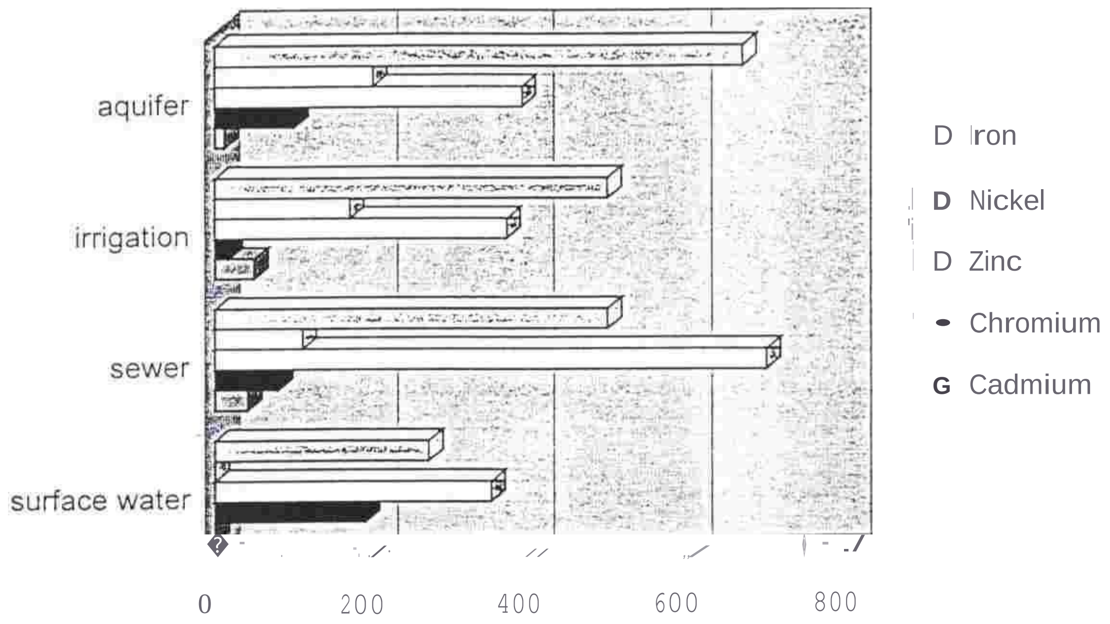

Figure 6.8

There is a genuine risk that the aquifer(s) quoted above is/are being contaminated with an excess of nickel (with a mean of 200 ug/L), and cadmium (a mean of 25 µg/L) that are above the acceptable limits of 100 and 20 ug/L respectively. Cadmium is also found in concentrations exceeding the consent limit of 20 µg/L as prescribed for irrigation and sewer. Accumulation of cadmium in soils in the vicinity of aquifers may result in high local concentrations in nearby waters, thus affecting drinking water which should contain no more than 0.01 mg/L.

There is also a threat to surface waters which are being contaminated with zinc (with a mean of 350 ug/L) and chromium (with a mean of 190 ug/L) that are well above the consent limits of 59 ug/L and 2 µg/L respectively. The limit of chromium is 0.05 mg/l for drinking water.

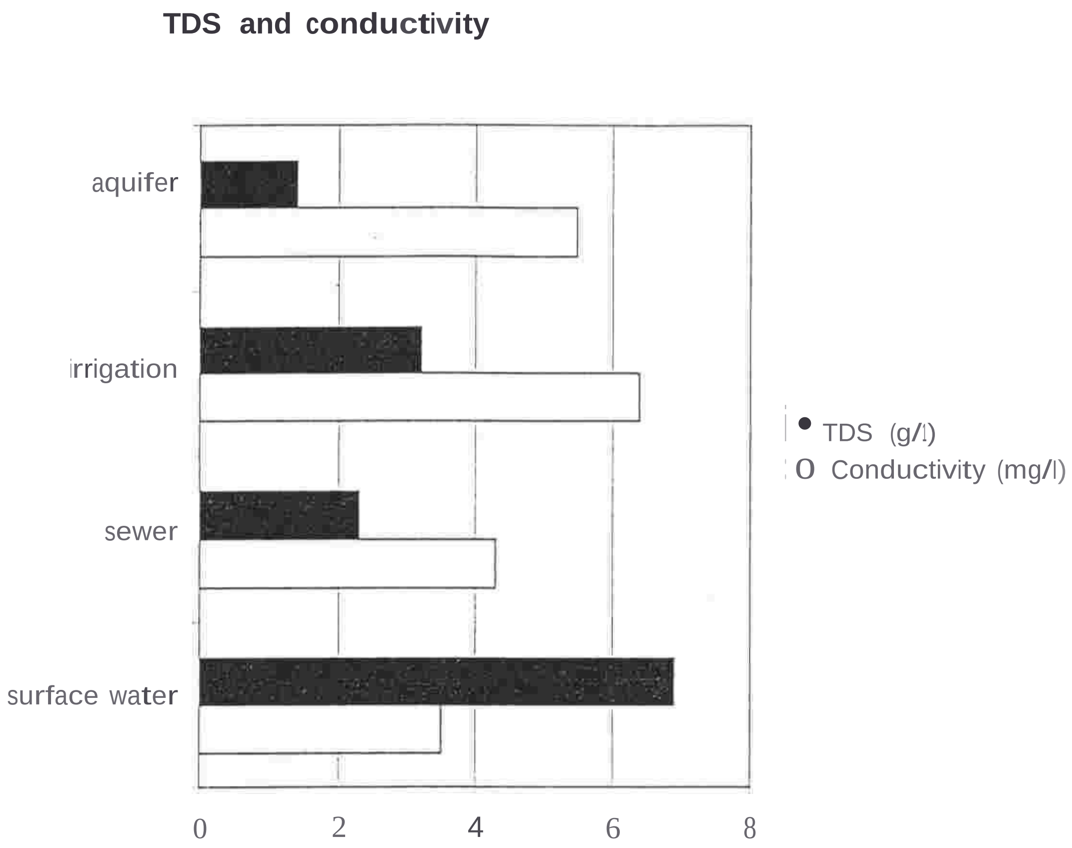

Figure 6.9

The TDS concentration of treated effluent is above the limits set for irrigation, aquifer and surface water and no limits available for sewer yet. High TDS values indicate the presence of an excessive concentration of some substances that would be aesthetically objectionable to the potable water consumer.

Conductivity (mg/L) is a characteristic of textile effluent that anses due to the presence of ionisable substances dissolved in water. It is approximately twice the TDS values (g/l). The conductivity parameter is not included in the Ministry of Environment guidelines for textile effluent.

Chapter 7

EFFECTIVENESS OF DYEHOUSE EFFLUENT TREATMENT PRACTICES IN MAURITIUS

7.1 Introduction

Dyehouse effluent from four textile plants with treatment facilities were analysed over a period of twelve months. The characteristics of the effluent before and after treatment have then been compared to measure the effectiveness of the treatment process. Furthermore a comparison of the different treatment methods is proposed in this chapter.

7.2 Methodology

Samples of dyehouse effluent were collected over the period August 1997 to August 1999 to assess the characteristics of the effluent from 4 dyehouses with treatment facilities. The following sampling plan was adopted to take care of short-term and long-term variations in the effluent:

- Samples collected per day before and after treatment: 4
- Sampling per week: 2

Various tests were then conducted on the samples to measure parameter like BOD, COD and heavy metals' content.

7.3 Results and Discussions

Tables 7.1 to 7.4 give the results of the tests performed on the effluent as well as the effectiveness of the treatment method. The latter is given as the % change in the measured parameter.

Table 7.1

Factory A: Cotton Knitted Fabrics: Reactive dyes

Parameter	Units	Before Treatment		After Treatment		%
		RV	*AV*	*RV*	*AV*	Removal
BOD	mg/L	160-420	260	70-200	101	61
COD	mg/L	380-1320	793	210-840	370	53
TSS	mg/L	120-350	228	20-130	66	71
pH		7.6-11.0	9.4	7.4-9.0	79	
TDS	g/L	1.1-5.1	3.7	1.8-3.0	[illegible]	32
Conductivity	mg/L	2.2-10.2	7.3	3.6-5.4	4.9	32
Cadmium	µg/L	<DL-100	45	<DL-70	24	47
Chromium	µg/L	<DL-0.1	0.02	<DL-0.04	0.01	50
Zinc	mg/L	0.08-1.25	0.62	0.07-0.8	0.31	50
Iron	mg/L	0.2-1.55	0.65	0.15-0.8	0.43	-34

Activated sludge method is used for treatment of effluent. The treatment at factory A is ineffective in bringing down most of the parameters to a level below the consent limits.

Table 7.2

Factory B: Cotton Woven Fabrics: Vat & Reactive dyes

Parameter	**Units**	**Before Treatment**		**After Treatment**		**%**
		RV	***AV***	***RV***	***AV***	**Removal**
BOD	mg/L	80-820	239	50-160	97	59
COD	mg/L	310-2230	1163	250-750	458	61
TSS	mg/L	0.03-0.45	0.197	0.02-0.2	0.07	64
pH		5-12.5	11	7.5-12	9.1	
IDS	g/L	0.3-9.0	**3.5**	1.4-4.8	2.8	20
TOX	µg/L	15-50	[illegible]	12-25	19	43
Conductivity	mg/L	0.7-18	6.8	2.8-9.5	5.5	19
Cadmium	µg/L	Nil		Nil		
Chromium	µg/L		0.27		0.44	31
Zinc	mg/L	0.06-0. 7	0.37	0.7-0.9	0.44	-26
Iron	mg/L	0.05-0.6	0.26	0.1-0.6	0.36	-38

The aerated pond method is used to treat the effluent at factory B. The pollutants are degraded aerobically in a pond. The treatment, here also, is quite ineffective in bringing down the level of most pollutants to below the consent limits.

Table 7.3

Factory C: Cotton Knitted Fabrics: Reactive dyes

Parameter	Units	Before Treatment		After Treatment		%
		RV	AV	RV	AV	Removal
BOD	mg/L	150-620	329	30-140	70	79
COD	mg/L	320-1800	973	80-230	180	82
TSS	mg/L	0.09-0.60	0.28	0.05-0.16	0.1	64
pH		8.0-11.5	10.3	7.6	9.8	8.5
TDS	g/L	1.0-3.7	2.4	2.9-3.6	3.2	-36
Conductivity	mg/L	2.2-7.5	48	5.8-7.1	6.4	-34
Cadmium	µg/L	15-110	54	<DL-105	49	9
Zinc	mg/L	0.2-0.7	0.47	0.25-0.45	0.37	22
Iron	mg/L	0.25-0.8	0.47	0.3-0.7	0.5	-6

Activated sludge method is used for treatment of effluent. The treatment at factory C is ineffective in bringing down most of the parameters to a level below the consent limits. Though removal efficiency of BOD, COD and TSS is better than factory A, where a similar treatment method is used, there is a major problem as far as the heavy metals' content is concerned, a situation far worse compared to factory A.

Table 7.4

Factory D: Cotton/Woollen Knitted Fabrics: Reactive dyes

Parameter	Units	Before Treatment		After Treatment		%
		RV	*AV*	*RV*	*AV*	Removal
BOD	mg/L	170-750	348	135-295	195	44
COD	mg/L	330-1215	553	215-590	375	32
TSS	mg/L	0.02-1.95	0.3	0.05-1.90	0.27	10
pH		4.6-12.2	8.7	7.5-11.5	9.5	
TDS	g/L	0.3-10.0	3.3	0.5-7.0	0.32	7
TOC	mg/L	70-570	218	70-1700	274	-26
TOX	µg/L	15-75	53	10-65	39	26
Conductivity	mg/L	0.5-20	6.5	1.1-13.1	6.0	8
Cadmium	µg/L		Nil		Nil	
Chromium	µg/L	0.0-0.3	0.13	0.0-0.4	0.18	-40
Zinc	mg/L	0.05-0.5	0.36	0.3-0.9	0.46	-28
Iron	mg/L	0.03-0.8	0.4	0.03-3.5	0.9	-122

A physico-chemical treatment based on flocculation is used for effluent treatment at factory D. The coagulants used are iron sulphate and aluminium sulphate. The removal efficiency at factory D is the lowest compared to the other factories surveyed. The level of pollutants in the treated effluent remains much above the consent limits.

7.4 Comparison of Treatment Methods

7.4.1 Physico-Chemical Treatment

The coagulants used are ferrous sulphate and aluminium sulphate. Table 7.5 indicates the removal efficiencies as observed in two treatment plants.

Table 7.5: Effectiveness of Physico-Chemical Method

Parameters	% **removal**
BOD	50
COD	41
TSS	99
TDS	-20
Conductivity	-19

BOD, COD and TSS have been reduced fairly significantly. The actual values of BOD and COD are well above the consent limits. No reduction has been observed for heavy metals in the effluent after treatment. The increase in the level of TDS and conductivity may be due to the addition of coagulants.

7.4.2 Activated Sludge Method

Table 7.6 indicates the efficiency of the activated sludge treatment as measured for three dyehouses.

Table 7.6: Effectiveness of Activated Sludge Method

Parameters	**% removal**
BOD	70
COD	68
TSS	68
TDS	-2
Conductivity	-1

This treatment method as practiced, in the three dyehouses, does bring down significantly BOD, COD, and TSS. Except for a reduction in the amount of Zinc and Cadmium, the level of heavy metals in the treated effluent remains unchanged. The removal efficiency is still not high enough to meet the consent limits for BOD and COD.

7.4.3 Aerated Pond Treatment

This treatment is carried out at only one dyehouse. Table 7.7 illustrates the effectiveness of this method.

Table 7.7: Effectiveness of Aerated Pond Method

Parameters	% **removal**
BOD	59
COD	61
TSS	64
TDS	20
Conductivity	19

The removal efficiencies of BOD, COD and TSS are in the range 60-65%. For heavy metals no reduction has been observed in the treated effluent. However this method is also ineffective as measured parameters such as BOD and COD levels remain well above the consent limits.

7.5 **Conclusions**

The effectiveness of all effluent treatment systems studied is inadequate with respect to essential parameters such as BOD, COD and some heavy metals that remain well above the consent limits.

The measured characteristics of the raw effluent indicate that TDS, TSS and iron content do not constitute a problem to the environment at discharge points.

For the effluent treatment methods considered above, factors such as pH, temperature, nature and amount of coagulant and the characteristics of the effluent are critical and have to be more closely monitored and controlled in order to improve the efficiency of the processes.

Chapter 8

MEASURES FOR POLLUTION PREVENTION IN DYEHOUSES

8.1 Introduction

This chapter includes a list of measures that the wet processing industry may adopt to reduce the effect of dyehouse effluent on the environment. The prevailing situation has been taken into consideration before the formulation of the proposals.

8.2 Proposals for Pollution Prevention

- *Management and Employee Commitment*

Companies should develop and adopt a comprehensive policy that definitively states their commitment to pollution prevention principles.

Experience has shown that employees are extremely knowledgeable about sources of waste and pollution in their facility and are an excellent source of ideas for reducing waste and preventing pollution.

Commitment is important, and a sustained effort at pollution prevention must be made over a long term to achieve complete results.

- *Technological Approaches*

A surprising number of successful pollution prevention ideas are based on simple, low technology principles such the training of employees. Initial pollution prevention efforts in a textile operation should focus on low-technology approaches, which have the highest return on investment and encourage further progress.

High-technology innovations are a far more effective long-term approach than "process tweaking." Orderly work practices pay big dividends in the short-term, but new technology, such as process modification is important for long-term success.

- *Right-First-Time Production*

One very important principle in textiles is right-first-time production, which reduces waste by avoiding chemically intensive adds and reworks. The amount of off quality production runs and reworks in Mauritian dyehouses varies between 10-20%.

- *Modification of Processes*

New, cleaner technologies and process alternatives can simultaneously reduce pollution and cut processing costs. Equipment manufacturers, responding to changing environmental priorities, are offering equipment (e.g., dyeing machines) that is more energy efficient, features reduced water consumption, accommodates recovery and recycle of waste streams, and allows for more precise control over operating parameters, an important factor in preventing pollution

Machinery selection and chemical selection are two ways of altering processes at the design stage to reduce pollution .

1. Machinery Selection: e.g. ULR dyeing machines, automatic dispensing systems.
2. Chemical Selection: e.g. chemical substitutions

Textile manufacturing is a chemically intensive process, so a primary focus for pollution prevention should be on textile process chemicals. Best management practices for preventing pollution involve substituting less-polluting chemicals where possible, as opposed to treating chemical-bearing waste streams. The supplier should take responsibility for providing adequate information that would enable mills to make reasonable environmental evaluations, even on proprietary products.

- ***Improved Process Control***

In the past, control systems in textile operations involved the automation of existing manual methods. In many cases, these methods have been enhanced with attractive graphic displays and other aesthetic improvements, but the underlying control protocol remains the same as with the manual methods. A new generation of innovative control systems is being developed that actually uses more capabilities of microprocessors. Some are hard automated systems, and others employ sophisticated fuzzy logic or neural network control strategies.

Some examples are:

> Automated mix kitchens

> Chemical dosing systems

> Direct dyebath monitoring and control systems

> Real-time sensors and advanced control strategies

> Real-time multichannel adaptive control systems

> Scheduling and management systems

- ***Appropriate Product***

Products should be designed to rrumrmse environmental impacts. For example selection of the proper yarn and knitting parameters, followed by tensionless handling of the fabric, ensures that the fabric ultimately achieves a relaxed equilibrium configuration. If the relaxed configuration meets customer specifications, then the need for chemical finishes is eliminated.

- *Production Area Layout*

An important pollution prevention design consideration is to avoid long runs of plumbing and pipes. Generally, material in these pipes becomes a waste with each changeover (e.g., of color, size). Multiplied by the number of changes that occur, this waste can be significant.

- *Enhanced Chemical and Pollution Prevention Expertise*

Current trends in textile management are toward flatter organizational structures. As a result, education and training of mill personnel are more important than ever because a greater need exists for technical understanding at the worker and first-line supervisor level.

1. Training

Employee work practices and attitudes towards pollution are an important key to success in pollution prevention programs, especially for companies attempting rapid, high-impact startups. Employees should be educated from the beginning about how their jobs relate to waste and pollution.

2. Education

A more long-term approach to pollution prevention can be taken through formalized employee education. Education programs are more general and less job-oriented than training programs. There is a need for an in-depth understanding of chemistry, reaction kinetics, thermodynamics, fluid mechanics, and fine-particle technology among process designers. This knowledge is essential to pollution prevention and long-term improvements.

In general, most pollution prevention training is best conducted internally because job-related issues are very site-specific. On the other hand, general education can be conducted either internally or externally. Several useful external training and education mechanisms are:

> Conferences and meetings.
> Equipment and trade shows.
> Trade organizations.
> Televised education.
> Videotape training aids.
> In-plant courses by outside experts or plant technical personnel.
> Correspondence courses from textile colleges.
> Evening classes at community colleges.

- *Equipment Maintenance and Operations Audit*

Poorly maintained equipment leads not only to bad work, off-quality production runs, high reworks, and poor employee attitudes, but also to increased pollution. Preventive maintenance is the solution to these problems and can be accomplished through proper audits.

1. *Major Machinery*

Each machine should be inspected for integrity and proper performance at regular intervals.

2. *Leaks*

Proper leak control and preventive maintenance can avert 75 percent of all leaks (21). A leak of only three drops per second from a faulty seal can discharge 1,300 gallons per year to the environment. Housekeeping and maintenance are essential for leak control.

3. *Filters*

Maintenance of filters and filter media is another area in which to focus pollution prevention efforts. To be effective, filters must be cleaned on a regular basis.

4. *Automatic Chemical Systems*

Routine maintenance is essential for automatic chemical feed systems and equipment such as bulk chemical storage tanks, pumps, and valves. These systems are an excellent aid to pollution prevention because they tend to reduce routine working losses and small-scale spills. Bulk automated systems increase the chance of a catastrophic release of chemicals. Therefore, routine preventive maintenance for bulk automated chemical dispensing systems is essential.

5. *Calibrations of Chemical Measuring and Dispensing Devices*

Any device used to measure or dispense chemicals to a process should be regularly calibrated or verified for accuracy. This includes drug room scales and automatic dispensing systems, as well as other devices used to measure and dispense chemicals.

6. *Employee Input*

Employees are a vital source of information concerning equipment in need of repair. Employee reports should be addressed immediately, not only to correct equipment problems, but also to convey management's commitment to pollution prevention, which will hopefully translate into worker commitment.

- *Quality of Material Input*

One important fact to realize is that the most frequently touted techniques for pollution prevention (i.e., right-first-time production and process optimization) depend completely on raw material consistency as a foundation. Without a uniform, consistent raw material input, constant process adjustments and changes must be made in a never ending (and never successful) quest for optimization.

- *Chemical Storage*

Chemicals should be stored according to manufacturers' recommendations and segregated according to type (e.g., oxidizer, reducer, acid, alkali, flammable). The facility design should include proper racks or other storage bins. Shipping, storage, handling, and delivery systems should be optimized to reduce spill potential and automated to improve dosing accuracy. Storage areas, where required, should be conditioned. Regular inventories should be carried out for obsolete chemicals.

- *Scheduling Dyeing Operations*

In dyeing operations, startups, stop offs, and color changes often result in losses of substrate, potential off-quality work, and chemically intensive cleanings for machines and facilities. Scheduling dyeing operations to minimize machine cleanings can have a considerable impact on pollution prevention.

- *Maintenance, Cleaning, and Nonprocess Chemical Control*

Chemicals used for maintenance and cleaning, such as solvents, are often among the most toxic, offensive materials found in textile mills. Many mills that have otherwise good pollution prevention programs overlook these chemicals, however. Because the chemicals are not used directly in production processes, they often escape the rigorous evaluation and prescreening those production chemicals must undergo.

- *Segregation and Direct Reuse*

One cornerstone of good waste management is that individual waste streams must be separately captured, segregated, and stored to maximize the potential for recovery, recycle, and reuse. This is true for waste streams from several textile-processing operations including preparation, dyeing, printing, and finishing.

- *Developing Markets for Wastes*

Wastewater, after treatment, can be used for irrigation bringing benefits for the textile industry.

- *Worker Training, Expertise, and Attitudes*

One vital piece of information that workers should be made aware of is which chemicals in that worker's area are potentially most harmful to the environment (e.g. metal-bearing dyes). The worker must be trained to be cautious about using these chemicals. Also, training must include correct procedures for pasting, dissolving, or emulsifying chemicals. These procedures should also be subject to closer auditing and record keeping.

- *Pollution Prevention Team*

A team that includes both management and supervisory personnel will be responsible for evaluation of pollution prevention programs and the implementation of corrective measures. Examples of the tasks of the team will include prescreemng of raw materials, ensuring proper documentation of accomplishments and developing an evaluation policy.

Textile facilities should set internal goals and document their progress. By documenting and publishing their success, they provide further stimulus to other facilities to investigate pollution prevention.

- *Standard Tests, Methods, and Definitions*

Transfers of pollution prevention ideas and cleaner technologies produce successful results and require minimal cost and effort. Standardization of tests, terminology, and reporting formats is a useful tool for achieving successful transfer of information. Standardization also reduces potential dis-information and misunderstandings about processes and products.

APPENDIX

SURVEY FORM

Company Name:

Total Number of Employees in Dyehouse:

1. Consumption of dyestuff in kg

    Reactive (Cotton)
    Vat
    Direct
    Pre-metallised
    Chrome
    Reactive (for wool)
    Others, specify

2. The amount of textile material processed in kg:

Fiber	Cotton	Wool	Polyester/ Cotton	Others/Specify
Yarn				
Fabric				
Garment				

3.1 Dyeing Machines and their specifications

Type	Quantity	Capacity	Liquor Ratio	Year of Manufacture	**Microprocessor** Control (YIN)
Winch					
Jet					
Cone Dyeing					
Fiber Dyeing					
Garment					

3.2 Continuous Process

[redacted] Trough Capacity

Padder

Jigger

Others (Specify)

4. Consumption of Auxiliaries in Kg

Auxiliaries	Quantity
Salt	
Acid Alkali	
Surfactants	
Sequestrants	
Wetting Agents	

5. Consumption of Water:

6. Do you feel there is a need to improve the technological level of dyehouse activities (Y/N):

7. Any measures taken in the past/being taken or planned to be taken to reduce the effect of dyehouse activities on the environment?

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8. Can you suggest measures that can be taken at national level/governmental level to encourage companies to treat their effluents?

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9. Are there any pressures from customers as to the use of certain chemicals or processing methods that may have an impact on the environment?

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