Study on Effluents from Selected Sugar Mills in Pakistan: Potential Environmental, Health, and Economic Consequences of an Excessive Pollution Load

NADIA M. AKBAR AND MAHMOOD A. KHWAJA

Sustainable Development Policy Institute (SDPI)
Islamabad, Pakistan

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TABLE OF CONTENTS

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ACRONYMS

AJK	Azad Jammu and Kashmir
BOD	Biochemical Oxygen Demand
BOD_5	Biochemical Oxygen Demand for a period of five days
COD	Chemical Oxygen Demand
CPC	Cleaner Production Center
DCDS	Double Carbonation Double Sulphitation
DO	Dissolved Oxygen
DRC	Defecation-Remelt-Carbonation
DRCS	Defecation-Remelt-Carbonation & Sulphitation
DRP	Defecation-Remelt-Phosphitation
DRPS	Defecation-Remelt-Phosphitation & Sulphitation
DRR	Defecation-Remelt-Recrystallization
DRS	Defecation-Remelt-Sulphitation
DS	Double Sulphitation
SOx	Oxides of sulfur
EPA	Environmental Protection Agency
EPO	Environmental Protection Orders
ESC	Environment Standards Committee
ESCAP	Economic and Social Commission for Asia and the Pacific
ETPI	Environmental Technology Program for Industry
GAC	Granular Activated Carbon
GOP	Government of Pakistan
NO_x	Oxides of nitrogen
NCS	National Conservation Strategies
NEAP	National Environmental Action Plan
NEQS	National Environmental Quality Standards
NORAD	Norwegian Organization for Development
NWFP	North West Frontier Province
PEPA 97	Pakistan Environmental Protection Act, 1997
PEPC	Pakistan Environmental Protection Council
PM	Particulate matter
PSMA	Pakistan Sugar Mills Association
RISNODEC	Research and Information System for the Non-Aligned and other Developing Countries
Rs.	Rupees
SDPI	Sustainable Development Policy Institute
SMART	Self Monitoring and Reporting Tool
SS	Suspended Solids
TDS	Total Dissolved Solids
TKjN	Total Kjeldhal nitrogen (organic nitrogen plus ammonia nitrogren)
TSS	Total Suspended Solids
UASB	Upflow Anaerobic Sludge Blanket

UN	United Nations
VOC	Volatile organic matter
WTO	World Trade Organization

ABSTRACT

Pakistan's 77 sugar mills comprise a major industrial sector in the country, with reported production of four million metric tons of sugar during 2003-2004. In the absence of adequate pollution control measures, such a large operation brings with it the potential for significant environmental and health concerns. In addition to releases of substantial levels of air and solid waste pollutants, a major environmental challenge posed by sugar production is the large amount of pollutant-laden wastewater produced.

Nearly all stages of sugar production - occurring at the mill house, process house, boiler house, cooling pond and distillery (for mills that also produce industrial alcohol from molasses) – are water intensive, discharging waste water containing high levels of oil, suspended solids, organic matter, and chemicals. A typical wastewater management practice employed by industrial management in the country is the improper use of unlined lagoons, a potential source of contamination of underground drinking water supplies.

For the present study, sampling of water effluents was conducted at a few sugar mills in the provinces of Punjab and Sindh and the effluent samples were examined for pH, total suspended solids (TSS), total dissolved solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), oil and grease content, and temperature. The analytical data revealed that the observed values of TSS, BOD, COD and oil and grease were higher than Pakistan's National Environmental Quality Standards (NEQS).

This paper explores the health and environmental impacts of waste water releases from the sugar industry, particularly in terms of pollutant parameters that are found to exceed NEQS; the amount of pollution charge, as calculated under the notified government environmental rules and regulations, that the industry will have to bear over the years if it fails to comply with NEQS; and the international trade implications of not meeting environmental standards. It also appraises the technical and regulatory context in which the wastewater problem may be tackled, discussing existing environmental policies and legislation and available options including technologies for the reduction of wastewater volume and pollution load, end of pipe treatment, and recycling/reuse of waste water.

1. INTRODUCTION

Pakistan's sugar industry, considered to be one of the best organized industrial sectors in the country, is also among the country's leading economic enterprises, directly or indirectly employing over 10 million people (Hagler Bailley, 1999). Comprising 77 mills, 38 in the province of Punjab, 32 in Sindh, 6 in the North West Frontier Province (NWFP), and one in Azad Jammu and Kashmir (AJK)[1], the industry produced nearly four million tones of sugar during 2003-04 and has a full production capacity estimated at five million tones, well exceeding the estimated domestic demand of 3.6 million tones (GOP 2002-03). Almost the entirety of the sugar output is used domestically while molasses, a by-product of sugar production, is mostly exported to other countries. A few sugar mills also use part of the molasses to produce industrial alcohol (ethyl alcohol) a significant quantity of which is exported[2].

Pollution control measures for such a large-scale industrial operation must be carefully planned to minimize risks to health and environment. The sugar production process is known to produce substantial levels of solid waste, water, and noise pollution. The highly polluted wastewater from sugar mills, in particular, poses a substantial danger to health and environmental quality. Chemical analysis of effluent samples from a number of sugar mills around the country revealed the presence of several water pollutants in amounts exceeding National Environmental Quality Standards (NEQS). The ensuing discussion and analysis explores the implications of these results.

[1] While the sugar production capacity of Pakistan encompasses 77 mills, not all of these are always in operation. For the past few years, 71 have been active – 38 in Punjab, 28 in Sindh, and 5 in NWFP (PSMA, 2004, 21-23).

[2] In the fiscal year 2003-04, 4,020,806 tones of sugar were produced in Pakistan, 116,175 tones of which were exported. 2,122,099 tones of molasses was produced, 1,457,283 tones of which was exported. 35,921,065 litres of ethyl alcohol was exported (PSMA 2004, pp. 24, 30-32) while the estimated total production capacity of the 10 distilleries in Pakistan attached to sugar mills is 143,000,000 litres. Actual ethyl alcohol production is probably significantly less than total capacity because two of the ten distilleries are not currently in operation (Dawn 2005).

2. SUGAR PRODUCTION

2.1 PROCESS

Sugar is mainly extracted from sugar cane and beet. The majority of sugar in Pakistan is produced by crushing and processing sugar cane, with only three mills in NWFP producing sugar from beet.[3] In 2003-04, 1,074,700 hectares of agricultural land was used to grow sugar cane yielding 53,800 tones, with an average yield of 49.7 tones per hectare of which 81.19 % was utilized by sugar mills (PSMA, 2004, 27). The actual sucrose content of sugar cane and beet varies with location and permanent harvesting conditions as well as yearly variable conditions such as water availability. Sugar recovery depends on both the processing technology and composition of the raw materials. Sucrose typically comprises 8 – 15 percent of the juice first extracted from the sugar cane (see Appendix A for a breakdown of sugar cane contents).

The sugar cane is harvested by cutting the stem, typically by hand in Pakistan and most parts of the world, and the roots are left for re-growth. There is a high priority on immediate delivery of the cane to the mill and to begin processing it as soon as possible after harvesting because the sucrose content deteriorates rapidly via enzymic, chemical, and microbial processes. Dependent on the harvest season, sugar mills are in operation only from around early November to April or May.

Sugarcane processing is aimed at isolating from the cane juice, which initially contains soil, fibres, and other non-sugar components, the purest form of sucrose possible with minimum wastage through destruction of the sucrose. The process is initiated with unloading, washing, and cutting the sugar cane, after which the desired end-product, refined white sugar, is produced in a two step procedure – in the first stage, juice is extracted from the sugar cane and converted to raw sugar; in the second stage, the raw sugar is refined to produce white sugar.

[3] In 2003-04, 23,797 tons of sugar was produced from 250,171 tones of beet and 3,997,010 tones of sugar was produced from 43,661,378 tones of sugar cane.

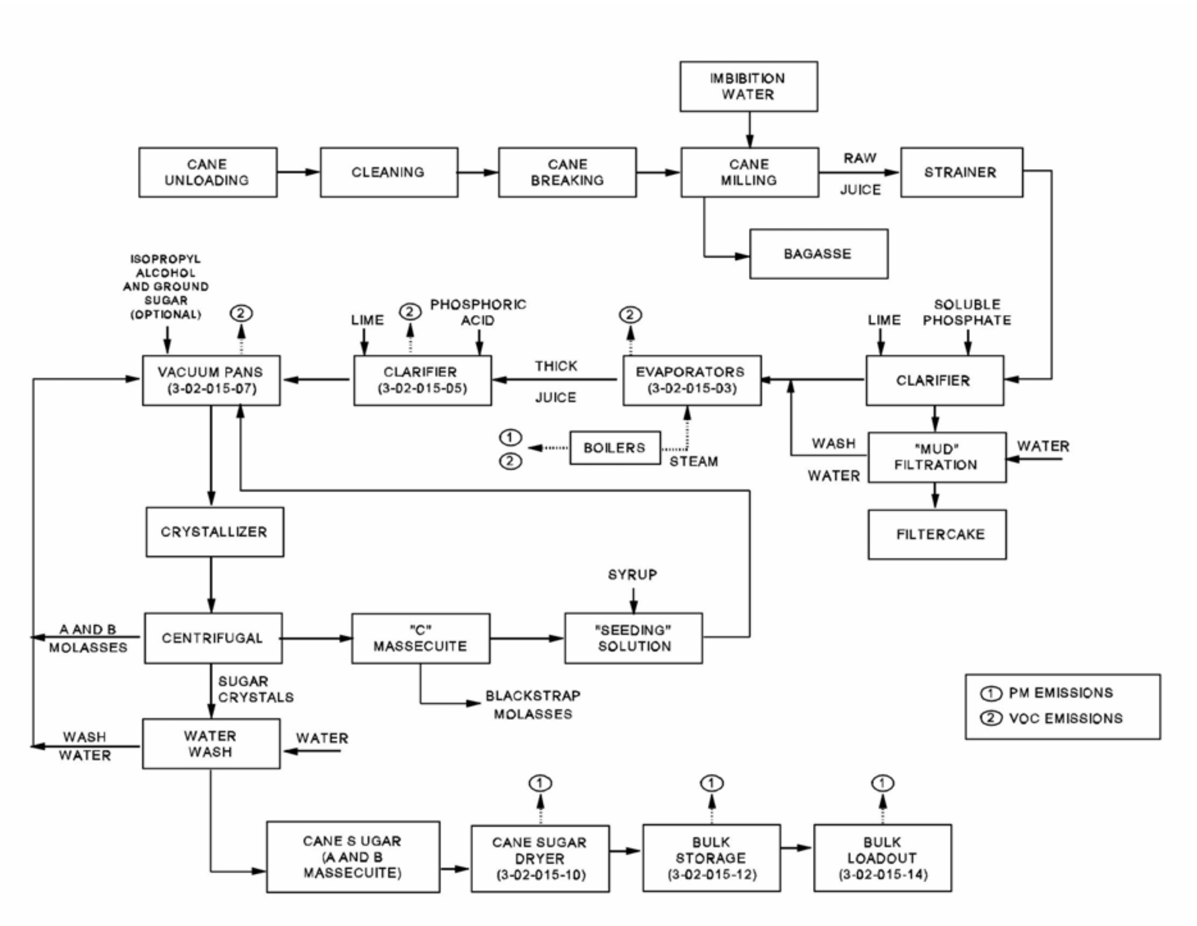

Figure 1: Cane Sugar Production. ***Source - U.S. EPA, 1997***

With some minor variations, the process of cane juice extraction and raw sugar production is relatively similar across the industry. A series of roller mils are used to crush and grind the cane. The residual fibre, called bagasse, is used as fuel for the boilers. The juice from the mill is generally clarified with heat or slaked lime, a process called “defecation”, which precipitates much of the impurities in the form of an insoluble mass termed “Mud” which is separated via gravity or centrifuge and then filtered. Polyelectrolytes may also be added before filtration to further coagulate suspended particles.

The clarified juice is passed on to the evaporators where it is first concentrated through steam evaporation and then boiled in large vacuum pans until the syrup is saturated enough for crystallization to begin. The crystallization is often initiated with a sprinkling of sugar dust. After crystallization, the mixture of sugar crystals and mother liquor is centrifuged and the separated crystals are washed with water. The centrifuged mother liquor or “molasses” is repeatedly reintroduced to the evaporator stage to remove the maximum sugar content possible until the molasses has been reduced to a solution of much lower purity which becomes one of the by-products, used mainly as cattle food or for ethanol production in distilleries. At this point, the raw sugar is either cooled and packaged or sent directly to the refinery in an integrated facility.

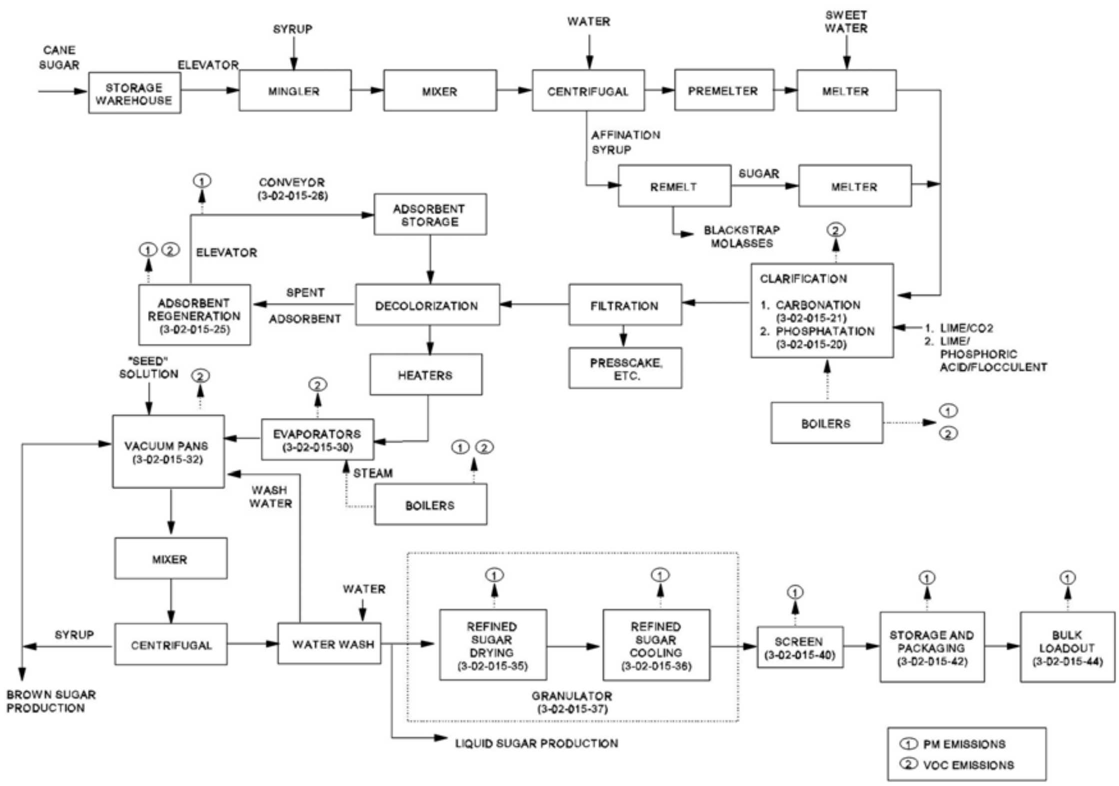

Figure 2: Refined Sugar Production. ***Source - U.S. EPA, 1997***

There are multiple sugar refining processes employed due to variations in methods chosen for clarification and decolourisation. Appendix B shows the relative use of various methods employed by sugar mills in Pakistan[4].

2.2 CHEMICALS USED

While the desired product, sucrose, is fully formed and present in the sugar cane or beet, the process of extracting the purest and most refined form of the sucrose from amongst the other components of the raw material, involves the use of a number of chemicals which eventually find their way into the wastewater stream. The following are the main chemicals used:

[4] Information on sugar production process from: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, "Sugarcane Processing," Chapter 9: Food and Agricultural Industries In *AP 42: Compilation of Air Pollutant Emission Factors*, vol. 1, 5th Ed., (Research Triangle Park, N.C.: U.S. EPA, June 1997). Accessed August 5, 2005: http://www.epa.gov/ttn/chief/ap42/ch09/bgdocs/b9s10-1a.pdf; Sugar Knowledge International (SKIL), "How Sugar is Made" and "How Sugar is Refined." Accessed July 14, 2005: http://www.sucrose.com/

Calcium Hydroxide (milk of lime, $Ca(OH)_2$): $Ca(OH)_2$, generated by sugar mills through conversion of calcium carbonate to calcium oxide or directly from calcium oxide, is used in the clarification step, a process termed as "Defecation", to coagulate colloidal matter and precipitate impurities into an insoluble mass which can be separated.

Carbon Dioxide (CO_2): In processes that employ carbonation for clarification of the raw sugar melt, CO_2 from the wet scrubbing unit of the boiler stacks or from calcination of limestone in the lime kiln, is bubbled through the liquid to precipitate impurities.

Phosphoric Acid (H_3PO_4): In processes that employ phosphitation for clarification, phosphoric acid is added to the sugar mixture to separate impurities. It may also be added before liming to sugarcane juices deficient in phosphorous pentoxide (P_2O_5) to hasten the settling of precipitated impurities.

Sulphur Dioxide (SO_2): In processes that emply sulphitation for decolourisation, the sugar melt is treated with SO_2 obtained through burning sulfur rolls in a kiln.

Polyelectrolytes: Polyelectrolytes are added to coagulate impurities precipitated during defecation and clarification.

Polyacrylamide flocculent: Polyacrylamide flocculent refers to synthetic organic polymers used in sugar processing to separate impurities in the form of a floc that can be skimmed off the surface of the cane juice.

Caustic Soda (NaOH), Soda Ash (Na_2CO_3), and Hydrochloric Acid (HCl): Accumulated scale from multiple effect evaporators and vacuum pans is removed by boiling a cleaning solution containing 30-35% caustic soda and 6-8% soda ash in the heaters, followed by rinsing with a solution containing 3.5% hydrochloric acid and finishing off with a water rinse.

Lead Sub Acetate: Lead Sub Acetate is a toxic chemical used to analyze sugar content[5].

Refer to Appendix C, Table C-1 for percentage amounts of chemicals used.

2.3 By-Products

The following are the major by-products of the sugar production process:

Bagasse: The remnant of the cane fibre, bagasse constitutes about 30% of the total sugarcane processed and contains approximately 50% moisture. The bagasse is used as fuel in the mill, meeting more than 90% of the fuel requirements for boilers.

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[5] Information on chemical use in sugar mills from: Environmental Technology Program for Industry (ETPI), "Environmental Report on Sugar Sector" *Monthly Environmental News* 5 Issue 7 (July 2001): 11-27; Hagler Bailley, *Pollution Prevention and In-Plant Control Measures in Sugar Mills – A Guidebook for Technical and Operational Staff* (Islamabad: Sustainable Development Policy Institute (SDPI), 1999).

Bagasse can also be used for the production of pulp and paper (Hagler Bailley-SDPI, 1999).

Mud or filter cake: Solid precipitates collect in vacuum and press filters after carbonation and clarification processes. The amount generated is about three per cent of cane from processes using sulphitation and about 7 per cent from processes using carbonation. Mud from the sulphitation process is mainly used as a fertilizer whereas the disposal of carbonation press mud can be a problem. It is often used to fill low-lying land. Another potentially recoverable by-product of the sulphitation process is sugar cane wax, comprising 8-10% of the sulphitation mud (UN ESCAP, 1982).

Molasses: The major by-product of the cane sugar industry, molasses, is produced in the amount of around 4.85 % of cane (UN ESCAP, 1982). It can be used as such as a type of sweetener, as cattle feed and to produce industrial alcohol.

Refer to Appendix C, Table C-2 for the percentage amounts of each by-product.

2.4 DISTILLERY OPERATIONS

Some sugar mills have attached distilleries to convert the molasses into industrial alcohol. Before commencing with fermentation, water and certain additives are added to the molasses to provide the optimum nutrient and pH environment for the selected yeast that is brought in from the culturing and recovery stations. The yeast is separated and sent back to fermentation tanks and the rest of the liquor is pumped up to the higher temperature upper section of the boiling column. Alcohol vapors are separated from the mixture in a number of steps and sent to the rectification column where they are collected and purified and alcohol of 96.2 % purity is removed from the top through a condenser (Hagler Bailly-SDPI, 1999).

2.5 WATER CONSUMPTION AND WASTE

2.5-1 Water Use:

Sugar processing requires hot water for a number of steps – such as water for imbibition, raw sugar remelting and various washings – in the amount of approximately 50% by weight of the cane crushed. Once steam generation has begun, about 90% of this need is met through condensate collection from the evaporators and overflow from the boiler house. The water content from the sugar cane itself also enters into this process. Water exits this loop through multiple means – in the filer cake, molasses, bagasse and irrecoverable vapors – with the largest portion going to the drain, in the amount of approximately 90% of the cane used[6]. See Appendix C, Table C-3 for sources of water input and loss.

[6] These percentages have been calculated from absolute numbers based on a sugar mill operation crushing 4,000 tons of sugar per day. Such an operation was found to require 1,980-2,000 tons of hot water/day, collect 1,800-1,850 tons of condensate vapors/day, intake approximately 2,760 tons of water from the cane and dispose 1,802 tons to the drain.

2.5-2 Water Effluents:

Wastewater with varying levels of pollution load is generated at nearly all stages of sugar production. Cane washing becomes necessary when the cane is harvested mechanically, generating waste water that has a high concentration of suspended solids and may have a significant sugar concentration due to damage incurred by the cane during mechanical harvesting.

Relatively mild effluents from the mill house, containing oil, grease, and some sugar content, are generated from the lubricating and cooling systems, floor washings, the large quantity of water used for juice extraction, and some leakage and spillover.

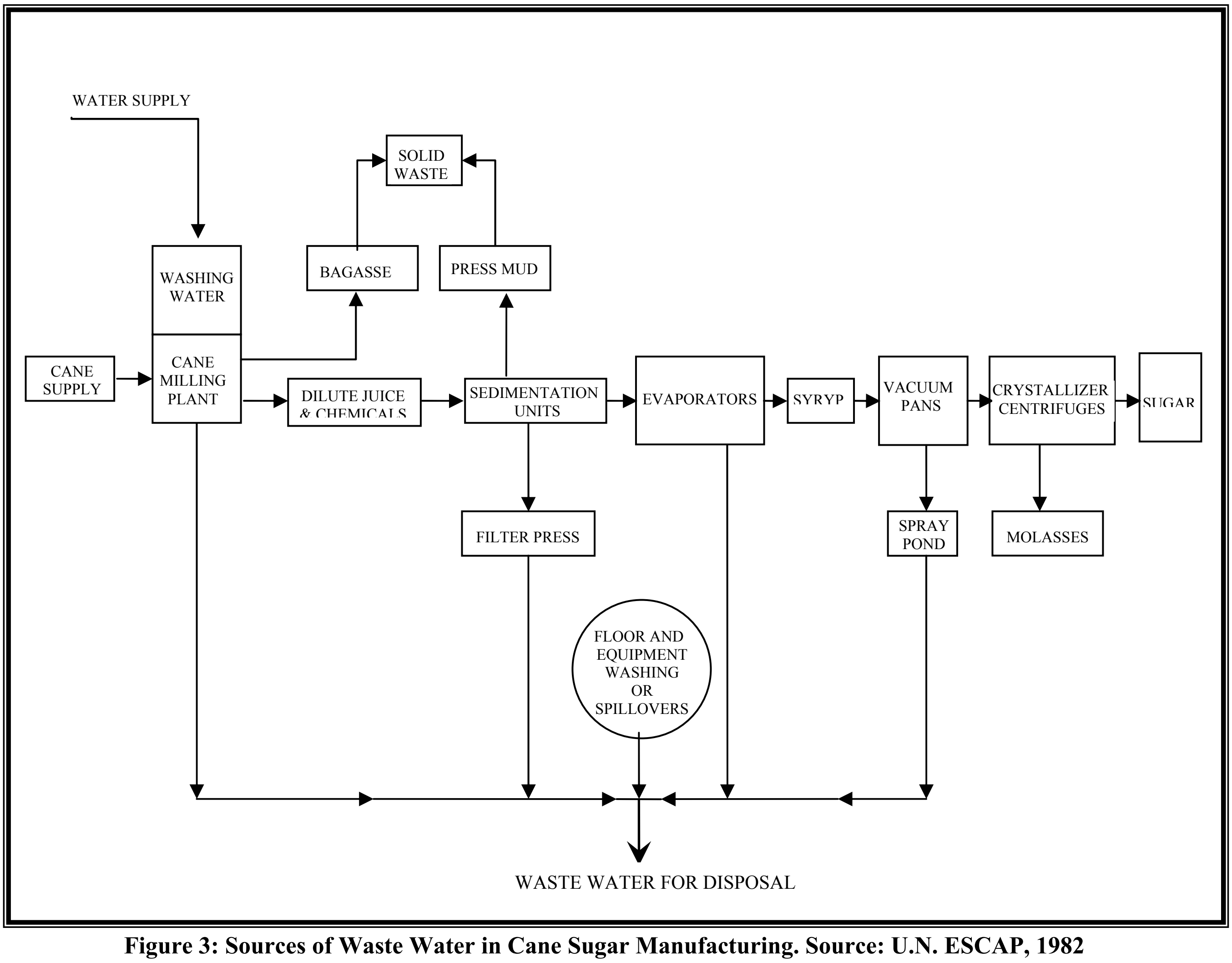

Figure 3: Sources of Waste Water in Cane Sugar Manufacturing. Source: U.N. ESCAP, 1982

A major source of organic pollutants in the wastewater is entrainment (the absorption of sugar particles into cooling and condenser waters) during evaporation and crystallization processes, which is reduced to some extent where entrainment separators are used in evaporators and vacuum pumps. Washing the filter cloths used for sludge from the clarifier increases the suspended solids concentration and BOD of the wastewater. The cleaning of juice heaters may add some caustic soda and hydrochloric acid to the wastewater. Combined with floor washings, which also add washing chemicals and more sugar, the process house effluents are considered more contaminated than effluents from the millhouse.

The boiler house sporadically discharges waste water from the carbon dioxide scrubbing unit, equipment leakage and floor washings which, though not voluminous, comprises of the most highly polluted component of the combined sugar mill effluents because of its very high BOD.

For mills that have an attached distillery, the numerous distillation stages produce a highly contaminated effluent, with BOD and COD concentrations of about 40,000 – 100,000 mg/l, called stillage. The rectifying column discharges a less contaminated effluent termed lutter (ETPI, 2001). Spills, leaks and overflow from molasses storage tanks can also cause a sharp increase in the pollutant load of the effluents.

In general, sugar mill effluents contain acidic and alkaline compounds, a significant concentration of suspended solids and a high BOD, COD, and sugar concentration[7].

2.6 ENVIRONMENTAL IMPACTS OF EFFLUENTS FROM SUGAR MILLS

Wastewater from sugar mills with its high BOD rapidly depletes available oxygen supply when discharged into water bodies endangering fish and other aquatic life. The high BOD also creates septic conditions, generating foul-smelling hydrogen sulfide, which in turn can precipitate iron and any dissolved salts, turning the water black and highly toxic for aquatic life.

A high COD, a measure of the inorganic and partly organic non-biodegradable content of the effluents, has effects on the receiving water body similar to that of a high BOD.

Suspended solids reduce light penetration and, as a result, plant production in the receiving water body by increasing turbidity and can also clog fish gills. Benthic decomposition of components can decrease oxygen availability while anaerobic decomposition can produce hydrogen sulfide and release by-products that increase BOD.

Total Dissolved Solids (TDS) refers to all dissolved materials present in the water. Combined sugar mill effluents generally do not have a TDS measure high enough to have an adverse environmental impact. Discharge of water with a high TDS level would have adverse impact on aquatic life, render the receiving water unfit for drinking, reduce crop yields if used for irrigation, and exacerbate corrosion in water systems and pipe (ETPI, 2001).

Highly colored water, besides being aesthetically unpleasing, limits light penetration, reducing production of phytoplankton and, by association, zooplankton, fish and dissolved oxygen supply.

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[7] U.N. Economic and Social Commission for Asia and the Pacific (ESCAP), "Section II: Sugar Industry," In *Industrial Pollution Control Guidelines* (Bangkok: 1982). Information on water effluents from: Hagler Bailley-SDPI, *Pollution Prevention and In-Plant Control Measures in Sugar Mills – A Guidebook for Technical and Operational Staff* (Islamabad: Sustainable Development Policy Institute (SDPI), 1999).

Effluents with a high temperature can be of concern if discharged to a small or confined water body causing a significant increase above the ambient temperature range or if the warm water attracts fish causing them to be affected by other components of the discharge. High temperatures also deplete dissolved oxygen levels in the water body.

Industrial effluents generally change the natural pH level of the receiving water body to some extent. Such changes can tip the ecological balance of the aquatic system, excessive acidity particularly, can result in the release of hydrogen sulfide to the air.

2.7 Current Waste Water Management

Currently, the wastewater is typically stored in unlined lagoons, posing a groundwater contamination problem, which is of particular concern in areas where drinking water comes from groundwater supplies. After some minimal settling of suspended particles and decomposition of organic content, the effluents are usually used for irrigation. The presence of oil and grease and pollutants may have an adverse impact on crop yields.

3. STUDY OF EFFLUENTS FROM SELECTED SUGAR MILLS

3.1 SAMPLING AND DATA COLLECTION

Effluents sampling was carried out during industrial surveys and on site environmental monitoring training program under technology transfer for sustainable industrial development project (TTSID 2000). Effluent samples were taken from sugar mills located in Punjab and Sindh provinces. As agreed with the managers and proprietors, the names/addresses of the studied mills are not disclosed in this paper. Standard procedures were used for the collection, transportation, storage and chemical analyses of the samples.

3.2 RESULTS AND DISCUSSION

The results are given in table1. Graphs comparing the pollutants levels of each parameter of the effluents among the five mills sampled and with the NEQS limits are given in appendix D.
Chemical analysis of the five effluent samples revealed the average TSS, BOD, COD, and Oil and Grease levels to be substantially above the National Environmental Quality Standards (NEQS). The average temperature was found to be around the maximum allowable temperature while the TDS level was found to be slightly below the NEQS and the pH value fell within the acceptable range (Table 1).

Table 1: Chemical Analysis (mg/L) of Effluent Samples

Parameters	SAMPLES					Mean	NEQS
	E00007	E00008	E00009	E00010	E00011		
pH value	8.100	6.500	9.200	7.900	7.020	7.740± 0.050	6-10
TSS	190.0	580.0	698.0	1092	300.0	612± 4.340	150.0
TDS	1354	1914	7264	1962	2560	3010.8± 28.01	3500
BOD	32.48	790.0	3258	1806	2225	1622.0± 11.89	80.00
COD	40.00	1380	3810	3800	3400	2494.0± 19.83	150.0
Oil and Grease	ND	309.0	398.0	11.00	1099	364.0± 2.920	10.00
Temp (^{o}C)	31.50	31.40	53.00	37.00	52.00	41.00± 3.070	40.00

The following graphs compare the pollutant concentration of each parameter of the effluents amongst the five mills sampled and to the limits set by the NEQS:

3.3 AREAS OF CONCERN

An excessive pollution load in the studied sugar mill effluent samples is a cause for concern on a number of fronts and for multiple stakeholders, ranging from the general public to the sugar producers. Amongst the many potential implications is the steady deterioration of the natural environment, increased risk to human health, imposition of penalties on the polluters, and diminished international product marketability.

3.3-1 Health and Environmental Impacts of Observed Pollution Load:

The high pollutant load of the sampled effluents, in quantities exceeding the NEQS limits many times over in certain parameters such as the BOD/COD levels, coupled with the large-scale sugar production in the country signifies that alarming levels of pollutants are regularly entering the environment.

The nature of sugar mill effluents poses the most critical danger to the natural ecology of the local water bodies absorbing the wastewaters, with more muted impacts also likely for the fertility of the agricultural land irrigated with the effluents and the populations exposed through using contaminated groundwater.

The potential affects of all the parameters that were measured in the samples collected for this study have been discussed in the preceding pages. The most notable revelation of the chemical analysis, the presence of an extremely high BOD and COD levels, portends acute adversity for the survival of aquatic life through a diminished oxygen supply and the production of toxic hydrogen sulfide. The resultant foul-smelling septic conditions would also render the water body a nuisance for local residents and spoil any aesthetic value of the natural environment.

The high BOD and COD levels are followed by substantial levels of suspended solids and oil and grease, many times over the NEQS limits. These high TSS levels further endanger aquatic life as they limit light penetration and, thereby, production of phytoplankton, the primary block in the aquatic food chain. The TSS and oil and grease can cause immediate fish kills through clogging fish gills. Agricultural yields may also be depressed through irrigation with effluents high in oil and grease content.

Though it appears that the ecological impact of Pakistani sugar mill effluents has not actually been studied thus far, parallels can be drawn with known scenarios in other regions because the nature of sugar mill discharges tends to be similar. One such documented case of intense ecological damage is the occurrence of extensive fish kills and adverse impact on cockles and shrimp breeding areas in the Mae Klong River in Thailand that received wastewaters from 12 sugar mills. The river began its recovery after the installation of a treatment plant in the late seventies (UN ESCAP, 1982, 9).

Beyond the ecological consequences, such spoilage of natural water ways has manifold potential social impacts such as hampering the livelihoods of local fishermen and farmers, curtailing any recreational uses, and casting a shadow on the civic responsibility of the polluting industry.

3.3-2 Compliance with NEQS and Pollution Charge

Companies that continue to discharge pollutants exceeding NEQS will eventually have to face a financial liability in the form of a "pollution charge" levied per unit of excess pollutant load. The concept of a uniform fine to be used as an enforcement mechanism to ensure compliance with NEQS was recommended by the Environmental Standards Committee (ESC) after extensive deliberations amongst industry, government, public interest, and academic representatives. The ESC was commissioned by the Pakistan Environmental Protection Council (PEPC) and housed at the Sustainable Development Policy Institute (SDPI) to update NEQS and devise the means for their implementation. The pollution charge regime is legally sanctioned by the Pakistan Environmental Protection Act 1997 (PEPA 97) and was approved at the 9th meeting of the Pakistan Environmental Protection Council (PEPC) in February 2001 to go into effect on July 1, 2001. Though this injunction has not been realized so far due to a delay in establishing a monitoring system without which pollution charges cannot be determined, the ground-work for the initiation of the monitoring system is mostly in place and polluting industries may very well soon find themselves faced with financial penalties (Khwaja, *Pollution Charge*, 2001).

The pollution charge is to be calculated at the rate of Rs. 50 per excess pollution unit for the first year and second year and Rs. 75 per excess pollution unit thereafter. Pollution units are determined for each regulated pollutant depending on its anticipated environmental and health impact. In order to facilitate and provide financial incentive for eventual compliance with NEQS, the pollution charge scheme is further graduated so that 20% of the applicable charge will be collected the first year of implementation, 40% the second year and 60% the third year[8].

Based on the average pollutant load of the sampled effluents, the potential pollution charge has been calculated for the three pollutants exceeding limits set by the NEQS[9]:

Table 2: Payable Pollution Charge Based on Average Pollution Load

Chargeable Parameters	Mean Pollutant Levels (mg/L)	Pollution Unit (Kg)	1st and 2nd Year Pollution Charges at Rs. 50/unit	Pollution Charge Beyond 2nd Year at Rs. 75/unit
TSS	612.00 ± 4.34	50	Rs. 574,585	Rs. 861,877
COD	2494.0 ± 19.83	50	Rs. 2,915,211	Rs. 4,372,816
Oil & Grease	364.00 ± 2.92	03	Rs. 7,337,775	Rs. 11,006,663
		Total:	Rs. 10,827,572	Rs. 16,241,356

8 For further information on the conception and regulatory details of the pollution charge system, consult: Khwaja, Mahmood A, Present *Status of Pollution Charge and Finalization of Rules* (Islamabad: Sustainable Development Policy Institute (SDPI), 2001).

9 For Pollution charge calculation formula, see Appendix E.

Table 3: Total Payable Pollution Charge of Combined Excess Pollutants.

Total Payable Pollution Charges at Rs. 50/unit	Total Payable Pollution Charges at Rs. 75/unit
Combined Pollution Charge: Rs. 10,827,572 Due 1st Year (20%): Rs. 2,165,514 Due 2nd Year (40%): Rs. 4,331,029	Combined Pollution Charge: Rs. 16,241,356 Due 3rd Year (60%): Rs. 9,744,814

It is expected that instead of paying huge amounts (Table 3) as pollution charge, industry will opt for in-house pollution prevention measures and end-of-pipe wastewater treatment in order to comply with environmental laws.

3.3-3 International Trade Concerns

In addition to heeding domestic environmental regulations, any business including sugar industry intending to export its product will have to be mindful of the direct and indirect environmental stipulations of an increasingly eco-conscious international market. This becomes a particularly problematic issue for many industries from under-developed or "southern" countries – often accustomed to lax environmental regulations from governments mainly focused on sustaining their struggling economies – attempting to obtain or maintain access to "northern" markets despite the plethora of restrictions and regulations. In addition to the quality and environmental product standards that most developed countries have extensive regulations for, there has been increasing pressure on northern governments to regulate imports based on process standards. To date, southern countries have been able to successfully challenge process restrictions on the basis that such encroachments on their domestic procedures are illegal trade barriers under World Trade Organization (WTO) rules (Khan et al., 2003).

However, in addition to formally enforced restrictions, business have to contend with another regulatory entity – a cadre of eco-conscious consumers exerting pressure for "voluntary" environmental protection through its buying choices. Though there may be room for under-developed countries to challenge process restrictions imposed by the governments of developed countries, increasing consumer preferences and shareholder constraints favoring environmentally benign processes and products will eventually place southern exporters at an impasse: they will have to adjust to environmental stipulations or lose those markets. Industries not currently exporting significant quantities may be blocked off from ever entering northern markets, whereas voluntary attention to eco-friendly production may win them a niche amongst socially conscious northern consumers often willing to spend more for eco-friendly products.

With such prospects on the horizon, it may be best for Pakistani producers to view environmental regulations not as a liability but an opportunity to improve efficiency and competitiveness in the international trading arena. A study by the Research and Information System for the Non-Aligned and other Developing Countries (RISNODEC) in India provides some support for such a stance. While being inconclusive about the relative costs and benefits of environmental compliance across the entirety of South Asia, in Sri Lanka the study found complying industries to not have endured any loss in international competitiveness due to compliance costs and surmised that pro-active environmental sensitivity presently would give a "first-mover" advantage to the country in the future. Though exports from South Asia continued to be rising regardless of environmental issues at the time of the study, failure to address such concerns now may affect exportability in the future (Khan et al., 2003).

The following categories describe various forms,- international environmental standards may take[10] for industrial products/industries including sugar industry:

Environmental Laws: Industrialized nations have an extensive body of laws concerning the health and environmental impacts of the composition, use and disposal methods of various products

Environmental Management Systems and Certifications: Consumers often use certification by internationally accredited agencies as an indication that a company attended to applicable legal obligations, environmental monitoring, information management, and improvement opportunities throughout the production process. The most widely used standard in Pakistan is ISO 14001 which assesses all types of establishments by uniform standards addressing short and long term environmental impacts of their products and covering measures ranging from pollution prevention and resource conservation to cost efficiency.

Eco-labeling: Eco labels provide information about the characteristics and environmental impacts of products, providing consumers the opportunity to make socially-conscious purchases while inducing producers to cater to market demands for eco-friendly production.

Codes of Conduct: Companies from industrialized nations often use codes of conduct specifying the type of standards they expect from suppliers in developing countries, with some large corporations crafting and monitoring their own criteria.

3.3-4 Unrealized economic benefits

Another incentive for sugar and other industries to work towards pollution prevention is a substantial but largely untapped potential for cost savings that accompanies pollution minimization measures such as increasing efficiency, utilizing by-products, recycling, and minimizing resource consumption. While cost-benefit analyses of environmental compliance by Pakistan's sugar industry are not available, the potential for financial savings can be gauged from surveying wastewater minimization attempts by other water-intensive industries.

One relevant prototype is the work of a Cleaner Production Center (CPC), funded by the Export Promotion Bureau and the Norwegian Organization for Development, (NORAD) that guided 16 tanneries in Sialkot through the process of in-house

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[10] For a detailed discussion, see Khan, Shaheen Rafi, Khan, Shahrukh Rafi, Khwaja, Mahmood A. and Qureshi, Mahvash Saeed, *The Costs and Benefits of Compliance with International Environmental Standards – Pakistan Case Study* (Islamabad: Sustainable Development Policy Institute (SDPI), 2003).

modifications to minimize waste generation and resource consumption. An initial review revealed combined annual savings of the 16 companies to amount to nearly Rs. 17 million, generating a profit of about 68% of what they invested for the improvements[11]. Many of the most successful measures parallel the type of management and process improvements required to increase efficiency in the sugar industry – equipment repairs to prevent leakage, process monitoring to reduce chemical use and water meter and grit screen installations to reduce wastewater volume and pollutant load. A drum repair to control leakage and chemical and water use, for instance, generated savings of Rs. 150,000 on an investment of Rs. 15,000 within the first month[12].

Albeit somewhat more elusive compared to the tangible cost savings generated by in-plant pollution prevention measures, end-of-pipe treatment can also generate substantial benefits as demonstrated by a tannery pollution control project in Kasur. The most appreciable benefit was the elimination of the stagnant pools of effluent after the introduction of a common pre-treatment plant, with the 400 acres of land rehabilitated for agricultural, residential, and commercial uses. Further, 311 acres of adjoining agricultural land will also be saved from contamination during monsoon overflows, bringing the total potential revenue from land reclamation to about Rs. 160.62 million[13] (Khan, et. al., 2003).

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[11] Combined capital investments of the 16 mills amounted to 9,989,250 and resultant combined savings for the first year to 16,751,750 or 67.70% of the investments.

[12] For a breakdown of investments and savings with regard to specific measures for each tannery, see Annex 1 of Khan, Shaheen Rafi, Khan, Shahrukh Rafi, Khwaja, Mahmood A. and Qureshi, Mahvash Saeed, *The Costs and Benefits of Compliance with International Environmental Standards – Pakistan Case Study* (Islamabad: Sustainable Development Policy Institute (SDPI), 2003).

[13] The value of the land reclaimed from removing the effluent pools was determined to be over Rs. 160 million at the rate of Rs. 400,000 per acre current at the time of the study. The adjoining agricultural land was being rented at Rs. 6,000 per acre. An incremental value of Rs. 2,000 per acre was predicted, bringing additional revenue to Rs. 0.62 million.

4. PAKISTAN'S LEGAL AND REGULATORY FRAMEWORK FOR INDUSTRIAL POLLUTION CONTROL

4.1 ENVIRONMENTAL LEGISLATION

The backbone of Pakistan's environmental protection system, PEPA 97 provides comprehensive legislative authority to address the range of environmental issues with its jurisdiction over all environmental mediums and grant of broad powers to regulatory bodies to implement any rules developed under the act.

The expansive coverage of the act is indicative in section 11, sub-section (1) which prohibits "the discharge or emission of any effluent or waste or air pollutant or noise in an amount, concentration or level" exceeding the National Environmental Quality Standards or any other standards established under the auspices of PEPA 97.

Under section 16, sub-section (1), the act also confers broad powers to federal and provincial environmental protection agencies to address any actual or potential violation of its injunctions by issuing Environmental Protection Orders (EPO) mandating "such measures that the Federal Agency or Provincial Agency may consider necessary within such period as may be specified in the order."

Relevant rules and regulations issued under PEPA 97 include:

- Certification of Environmental Laboratories Regulations, 2000
- Revised National Environmental Quality Standards, 2000
- Provincial Sustainable Development Fund Board Rules, 2001
- Environmental Samples Rules, 2001
- National Environmental Quality Standards (Self Monitoring and Reporting by Industry) Rules, 2001
- The Pollution Charge for Industry Rules, 2001

Pakistan has instituted the following strategies to streamline environmental protection efforts (Khwaja and Khan, 2005):

- The National Conservation Strategy (NCS, 1992)
- Provincial Conservation Strategies
- The National Environmental Action Plan (NEAP)

4.2 IMPLEMENTATION

Although the national and provincial regulatory agencies have broad legislative authority at their disposal, implementation of environmental standards has been sketchy due to a number of limitations including the extensive technical and financial resources required to set up a monitoring and enforcement system. However, the following mechanisms, the operating procedures for which have been developed in consultation with and notified to regulated industries, are expected to provide the requisite apparatus for implementation of NEQS:

4.2-1 Self-Monitoring and Reporting Program/SMART for Industry:

Enforcement of environmental regulations cannot proceed without a monitoring system, to which end a self-monitoring and reporting system has been conceived whereby industry will be responsible for reporting its own emissions. A software program titled “Self-Monitoring and Reporting Tool (SMART) has been developed to aid the uniformity and quality of reporting. The procedures will be further standardized by requiring sampling to conform to “Environment Samples Rules, 2001” and sampling laboratories to be certified under the “Certification of Environmental Laboratories Regulations, 2000.” Industries have been grouped into three categories based on the reporting frequency stipulated for each. For liquid effluents, group A is advised to report monthly, group B quarterly, and group C biannually. For gaseous emissions, group A is advised to report monthly and group B quarterly.

The sugar industry has been placed in category B, both for effluents discharges and gaseous emissions and will have to submit quarterly reports of its releases (Khwaja, 2001). Priority monitoring parameters for effluents under normal plant operating conditions are temperature, pH, BOD_5, TSS, COD, oil & grease, effluent flow and for gaseous emissions; particulates (both from process & fired equipment) CO_x, SO_x, NO_x (Khwaja and Quraishi,2003).

4.2-2 Pollution Priority Parameter Charge:

The levying of a penalty for environmental violations by industry in the form of a “pollution charge,” discussed earlier in more detail (Section 3.3-2), is authorized by section 11, sub-section (2) of PEPA 97 directing the Federal Government to “levy a pollution charge on any person who contravenes or fails to comply with the provisions of sub-section (1), to be calculated at such rate and collected in accordance with such procedure as may be prescribed.” Its graduated payment scale that increases penalty fees over a period of three years is expected to provide incentive for sugar and other industries to come into compliance with environmental standards.

5. Pollution Prevention and Treatment Options

The main options for dealing with the wastewater production of sugar mills consist of in-plant practices to reduce the production of wastewater, regulated land disposal, and end-of-pipe treatment.

5.1 Water Pollution Minimization Options

The largest array of available options that can bring about a substantial reduction in sugar mill effluents with relatively minor financial investments and the potential for cost-savings consist of in-house pollution prevention measures that entail improved management, technical adjustments, and recycling of resources.

5.1-1 Monitoring and Maintenance

Vigilant management practices are a key starting point in reducing the wastewater problem:

- Water conservation by

  1. Prevention or minimization of spills and leaks through regularly inspecting and repairing various units (pumps, conveyors, pipes, and other vessels) and handling and storing molasses properly because they have an extremely high BOD of around 900,000 mg/l (UN ESCAP, 1982).
  2. Monitoring of quantity and quality of incoming and outgoing water at the mill with flow meters measuring flow.

- Performance of sugar auditing to minimize product loss

5.1-2 Process Modifications

Minor changes in the sugar production and waste handling process can produce substantial reductions in wastewater volume and pollutant load:

- Mills should be operated at optimum capacity and with minimum stoppages because raw water consumption per ton of cane crushed increases when crushing lower than the optimum capacity and when hot water production is suspended during halts in operations (cleaning, restocking, and breakdowns).

- For maximum sugar sucrose recovery, condensate hot water should be used for imbibition because, otherwise, the presence of dissolved solids in the water increases the solubility of sucrose in the sugarcane juice. For optimum recovery, imbibition water should be maintained around 25-30% of cane used. However, increasing imbibition water from 15% to this optimum range increases hot water consumption (Hagler Bailley - SDPI, 1999).

- The TSS level of the wastewater is much less when the sugar cane is manually harvested.

- Cooling water from mill bearings should be separated from the effluents and the oil content removed using oil skimmers, achieving the recovery of lubricating oil and reduction of soil contamination when the effluents are used for irrigation.

- Minimizing the mixing of filter cake with waste water reduces pollutant content

- Entrainment can be minimized and sugar recovery increased with the use of efficient entrainment separators and mist eliminators in evaporators[14]

- Water conservation and sugar recovery can be improved by avoidance of overloading evaporators and vacuum pans, boiling at excessive rates, or operating at incorrect liquid levels

- Dirt and large particles in effluents can be minimized by allowing suspended particles in filter cloth washings to settle in a holding tank before being mixed with other effluents and screening wastewater before emitting to remove refuse, dirt, and remnants of the cane

- Caustic wastes from the cleaning equipment should be separated from the rest of the wastewater and gradually released into furrows and blended with the other effluents (ETPI, 2001).

5.1-3 Recycling

The recycling of water is the primary factor in reducing wastewater volume. Water use in a sugar processing operation tends to be about 20 times the amount of cane crushed, a consumption level that can be dramatically reduced to 0.9 times the quantity of cane used by utilizing all available recycling measures to about 1.3 times the cane consumption with some recycling. Some opportunities for recycling water include:

- Recycling of cooling and condenser water and flue gas washing water which is rendered clean through precipitation and filtration

- Collection and use of water contaminated with cane juice for imbibition, the application of water or juice to crushed cane to improve extraction of juice

- Minimization of floor cleaning water by using bagasse to “dry clean” floors and using water recovered from the production process to reduce fresh water usage

5.2 LAND DISPOSAL

Effluents from sugar cane mills are often used for irrigation and this is considered an apt measure if the wastes are first treated to remove oil and suspended particles and to correct the pH value. The water can also be used to irrigate any neighbouring sugar cane fields, making the sugar production process a closed loop system that

[14] Sugar mills in Louisiana, USA, reported recovery of up to 3 kg more sugar per ton of cane processed after the installation of stainless steel or monel demisters in the multiple-effect evaporators to eliminate sugar entrainment through condenser water (UN ESCAP, 1982).

utilizes its own wastes as inputs. However, there is the possibility of sludge accumulation and the development of an odour problem. This can be avoided by using only a third of available land for irrigation with effluents and by cultivating grain or vegetable crops on that land for the next two years. In certain cases, plowing furrows in the land can eliminate much of the odour problem (UN ESCAP, 1982).

5.3 WASTE WATER TREATMENT

Available end-of-pipe effluent treatment options include the use of lagoons, trickling filters, upflow anaerobic sludge blanket (UASB) reactors, and activated sludge treatment (sequential batch reactors). For a comparison of the characteristics and relative strengths and weaknesses of these technologies, refer to Appendix F.

The use of a sequence of lagoons is the standard treatment system in use. For areas where drinking water supplies come from groundwater, it is critical to properly line the lagoons to prevent groundwater contamination. One key drawback is that lagoons require large tracts of land. However, since most of the sugar mills in Pakistan are located in rural areas with availability of land, this is not considered a significant obstacle for the time being. The large volume and pollution load of the effluents from the sugar mills in Pakistan necessitate very costly lining options and extremely long retention periods in the lagoons. Moreover, these measures would still fall short of bringing the treated effluents into compliance with the NEQS.

A study initiated by the United Nations Economic and Social Commission for Asia (UN ESCAP) and the Pacific in 1982 concluded that treatment of wastewater in a two-stage process proceeding from an anaerobic lagoon to an aerobic lagoon or oxidation pond provided sufficient and economically feasible treatment of the effluents, citing pilot projects that achieved reduction of the BOD to 60 to 170 mg/l. The study findings preferred this option to others on the premise that a fully mechanized wastewater treatment plant takes about a month to reach stable operations and is therefore not economically feasible for an industry that only operates for about four to six months. It was acknowledged, nonetheless, that with decreasing land availability, in-house measures producing less voluminous wastewater with stronger BOD requiring more expensive lagoons and ponds, and the problem of ground water contamination, less land-intensive and more efficient systems may be needed in the future, such as the activated sludge process.

From amongst other technologies, the low efficiency trickling filters are probably not feasible for the high pollutant load of the Pakistani sugar industries. This option can perhaps be looked into if other measures such as in-plant pollution prevention techniques significantly lower pollutant load.

Activated sludge systems have the highest energy requirement for aeration which drives up operation and management costs. However, costs can be reduced by using this as a secondary treatment after effluents have been treated with Upflow Anaerobic Sludge Blanket (UASB) technology. The UASB system, a much cheaper option because it only requires energy to run a few aeration pumps, can potentially remove up to 80 – 90 % of the BOD_5[15]. The remaining BOD_5 level can be reduced with an activated sludge system, achieving the same removal efficiency at a much lower cost. A study by the Environmental Technology Program for Industry indicated that COD levels still remained above NEQS for some samples. This may be due the presence of oil and grease which can be removed by separating oily water streams in the mill. Further, improved in-house management may decrease the pollution load to a point rendering only UASB treatment necessary[16].

[15] BOD_5 refers to the quantity of oxygen consumed over five days through the biochemical decomposition of organic matter.
[16] For a detailed review of various treatment technologies, see Sustainable Development Policy Institute (SDPI), *End of Pipe Treatment for Sugar Mill Effluents – A Guidebook for Technical and Operational Staff*, (Islamabad: SDPI, 1999).

6. RECOMMENDATIONS

6.1 FOR SUGAR INDUSTRY

The first point of focus, not least because of the relative immediacy of results and minimal financial investment, should be in-plant pollution prevention measures. As an added incentive, such measures often generate substantial financial savings in addition to the environmental benefits, as demonstrated by the example of Sialkot tanneries[17].

Section 5.1 of this paper, titled "Water Pollution Minimization Options", provides a detailed treatment of various options available to streamline in-plant operations to minimize the volume and pollutant-concentration of water discharged. The main modes of intervention include water recycling, process modifications to decrease wastewater production, and improved in-house management such as water use monitoring and equipment maintenance to optimize wastewater reduction from the existing production processes. The various measures discussed have the potential to increase efficiency, decrease cost of operations and reduce wastewater volume and pollutant load.

Nonetheless, end-of-pipe treatment, though it will require a large capital investment and substantial maintenance costs, will eventually have to be adopted to bring the sugar industry in compliance with NEQS. If the sugar mills are vigilant with the in-plant pollution prevention measures, the wastewater can be substantially reduced rendering the requisite end-of-pipe treatment much less costlier than the scale of treatment that would be needed to mitigate current effluent levels. The financial burden per company can also be reduced if any clustered mills pool resources to create and maintain a collective wastewater treatment system. Moreover, the Kasur Tannery Pollution Control demonstration project has shown that the financial burden can be moderated with savings through other means such as the marketability of land reclaimed from standing wastewater. The sugar industry also has to keep in mind that eventually pollution charge will become a financial liability that will only be averted through complying with NEQS limits.
From the various options available, sequences of aerobic and anaerobic lagoons or a combination of UASB reactor and activated sludge system appear to be the most thorough and affordable options.

To enhance the identification and implementation of appropriate control measures, industry should consider carrying out periodic "waste audits", particularly for water use, to identify the level of waste discharge.

6.2 FOR GOVERNMENT

Government can encourage compliance with environmental standards by fostering favorable regulatory and financial conditions. It already has at its disposal broad

[17] Refer to section 3.3-4, "Unrealized Economic Benefits" for a discussion of potential economic benefits of waste reduction.

legislative authority under PEPA 97 and potent implementation tools in the form of the proposed Self Monitoring and Reporting/SMART Program for Industry and pollution charge system to which industry has itself contributed and acquiesced. The fruitfulness of these initiatives largely depends on government to actualize the launch of these tools and to ensure consistency in their enforcement.

Nevertheless, inducements to comply cannot succeed if businesses simply do not have the necessary resources. Government can facilitate industry's move to environmental stewardship by garnering resources to finance such initiatives in the form of subsidies for environmental technology, soft loans, and technology transfer assistance aimed at building capacity for environmental protection in developing economies. It can try to explore options available under capacity building provisions of international trade agreements, for instance, and leverage funding for demonstration projects similar to the Cleaner Production Center assisting the Sialkot tanneries and treatment plant project for Kasur tanneries.

Government agencies can also facilitate domestic initiatives and cooperation by providing forums and opportunities for stakeholders to come together and tackle environmental issues in collaborative processes, such as the one effectively executed for the determination of the pollution charge system and self-monitoring and reporting /SMARTprogram (Khwaja, 2001). In reference to the sugar industry, a multiparty initiative government could promote is examining the potential for a joint wastewater treatment system.

6.3 Further Studies of Relevance to Various Stakeholders

During our survey of existing literature and information to enhance the depth and breadth of our analysis and conclusions, the discovery of many gaps in availability of crucial data leads us to recommend further study in the following areas:

- Water testing, particularly of drinking water and groundwater around mills or in supplies containing the potential of contamination
- Health Assessment of populations known to be exposed to contaminated drinking water
- Ecological Studies to examine water quality of bodies receiving sugar mill effluents assessing factors such as occurrence of natural biodiversity, availability of dissolved oxygen (DO), BOD/COD, etc.
- Assessment of impact on local livelihoods through water testing of irrigation canals receiving effluents from sugar mills; controlled experiments examining agricultural yields and chemical make-up of produce irrigated with sugar mill effluents; and assessing impact of deteriorating aquatic systems on other means of livelihood such as fishing
- Cost-benefit analyses to study the impacts of instituting wastewater minimization and treatment measures considering factors such as cost of production and

profitability and direct and in-direct penalties of failing to comply with environmental standards

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APPENDIX A: COMPOSITION OF SUGARCANE JUICE AND ITS REFLECTION IN WASTEWATER PRODUCED

Parameter	Percentage (%)	Reflection in Wastewater
Water	70 – 72	Water
Fibrous Material	13 – 15	SS
Sucrose (organic matter)	8 – 15	BOD, COD
Reducing Sugar (organic matter	0.5 – 2	BOD, COD
Organic matter other than sucrose	0.5 – 1	BOD, COD
Inorganic matter (phosphates, chlorides, sulfates, nitrates, silicates, Na, K, Ca, Al, Fe, etc.)	0.2 – 0.6	TDS
Nitrogenous matter (Albuminoids, amides, amino acids, ammonia, xanthene bodies)	0.5 – 1	TKjN
Ash	0.3 – 0.8	SS

SS – Suspended Solids
BOD – Biochemical Oxygen Demand
COD – Chemical Oxygen Demand
TDS – Total Dissolved Solids
TKjN – Total Kjeldhal nitrogen (organic nitrogen plus ammonia nitrogren)

Sources: Hagler Bailley and Sustainable Development Policy Institute (SDPI), 1999

APPENDIX B: SUGAR PRODUCTION PROCESSES EMPLOYED IN PAKISTAN

Processes	No. of Mills 1976	No. of Mills 1992 - 93	No. of Mills 1996 - 97	Year of Introduction
Double Carbonation Double Sulphitation (DCDS)	20	10	4	1936 - 37
Double Sulphitation (DS)	1	1	-	1938 - 39
Defecation-Remelt-Recrystallization (DRR)	1	1	-	1971 - 72
Defecation-Remelt-Phosphitation (DRP)	1	13	24	1972 - 73
Defecation-Remelt-Carbonation (DRC)	2	25	21	
Defecation-Remelt-Sulphitation (DRS)	2	5	1	1972-73
Defecation-Remelt-Carbonation & Sulphitation (DRCS)	-	8	11	1977 – 78
Defecation-Remelt-Phosphitation & Sulphitation (DRPS)	-	-	5	NA
DRT	-	-	2	1985 - 86
Total Mills	**27**	**63**	**68**	

Source: *Monthly Environmental News,* 2001

APPENDIX C: SOURCES OF MATERIAL INPUTS AND OUTPUTS IN SUGAR PRODUCTION

Table C-1: Resource Consumption in a Typical Sugar Mill Operation

Chemicals	Consumption (as percentage by weight of cane)
Lime	0.15%
Sulphur	0.001%
Phosphoric Acid	0.003%
Polyelectrolytes	0.0003%
Fire wood	0.05%
Furnace oil	0.15%
Grease	0.00015%

Source: Hagler Bailley and SDPI 1999

Table C-2: Material Balance at a Typical Sugar Mill Operation:

Input/Output	Percent of Cane or Clarified Juice
Water added for imbibition	15.00% of cane
Bagasse produced	30.00% of cane
Press mud removed	3.00% of cane
Final molasses produced	4.85% of cane
Clarified juice obtained	85.00% of cane
Raw sugar produced	10.53 % of clarified juice
Refined sugar produced	8.50% of cane

Source: Hagler Bailley and SDPI 1999

Table C-3: Process Water Balance at a Sugar Mill Consuming 4,000 tons of Cane Per Day

Source	Tons of Water / Day
Water in:	
from Cane	2,760
from chemicals (milk of lime)	50
imbibition water	600
Water out in various by-products:	
with bagasse	600
in molasses	9.70
in filter cake	92.40
in vapors of last effect	298
in vapors from vacuum pans	617
Water going to drain:	1,802

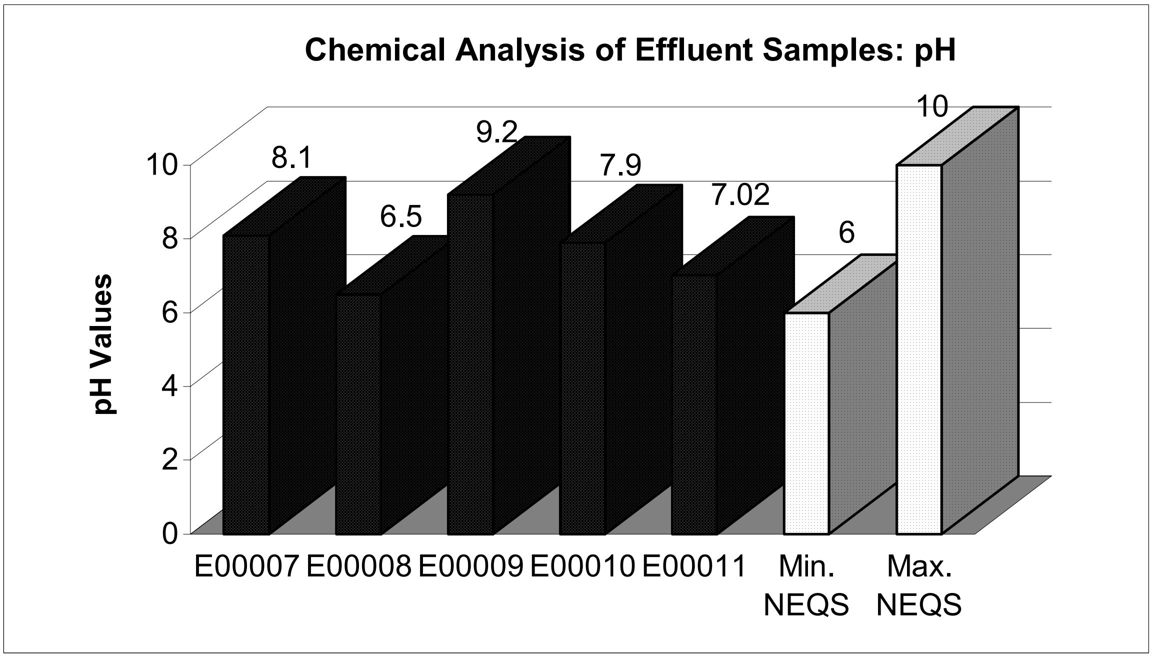
Source: Hagler Bailley and SDPI 1999

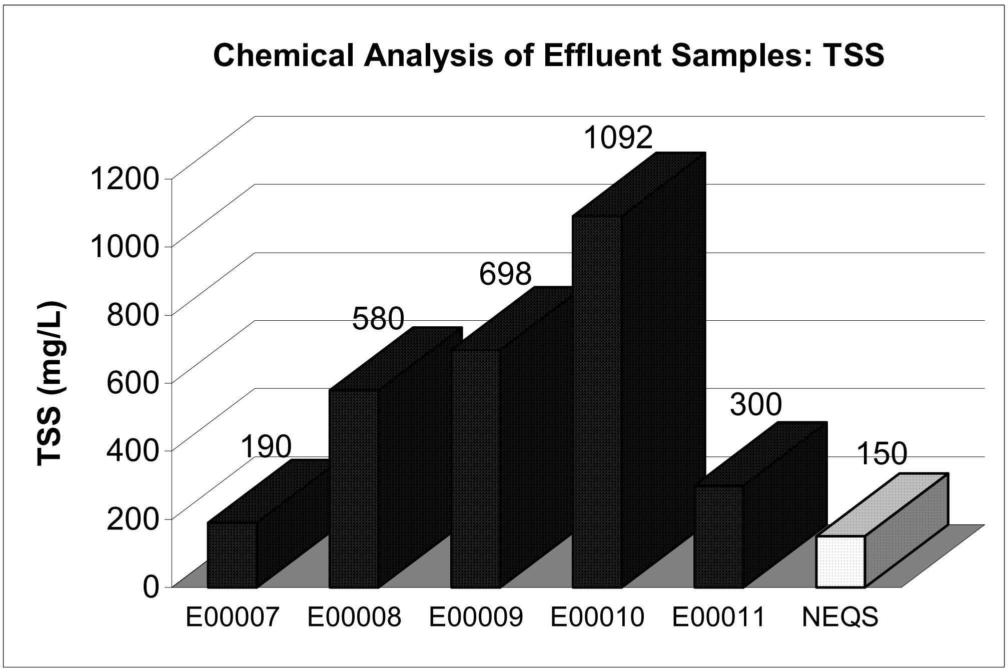
Table C-4: Wastes Produced During Sugar Production

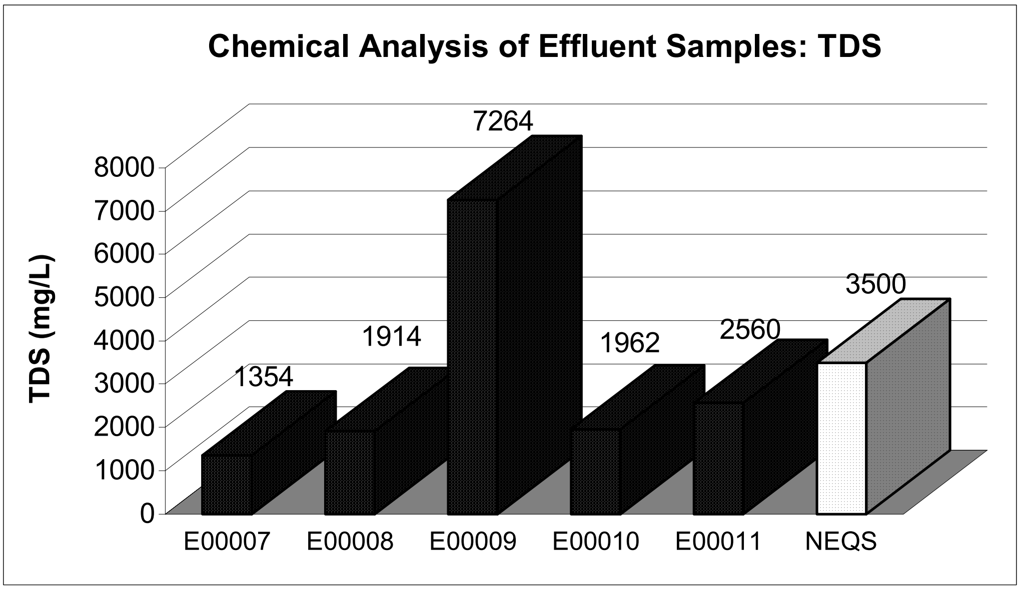
Process Stage	Main Inputs	Wastes and By-Products
Mill House	Sugarcane	• Wastewater containing suspended solids and oil content • Washing from floor cleaning containing sugar • Bagasse
Process House	Sugar Juice	• Filter cake • Washing of different components such as evaporator, juice heater, vacuum pan, clarifiers, etc., generates aggressive effluents with high BOD_5, COD and TDS concentrations
Boiler House	Bagasse and Furnace oil	• Fly ash • Smoke • Flue gasses • Wastewater from scrubbers
Cooling Pond	Water and Chemicals	• Wastewater
Distillery	Molasses	• Wastewater (stillage) containing very high BOD_5, COD and suspended solids

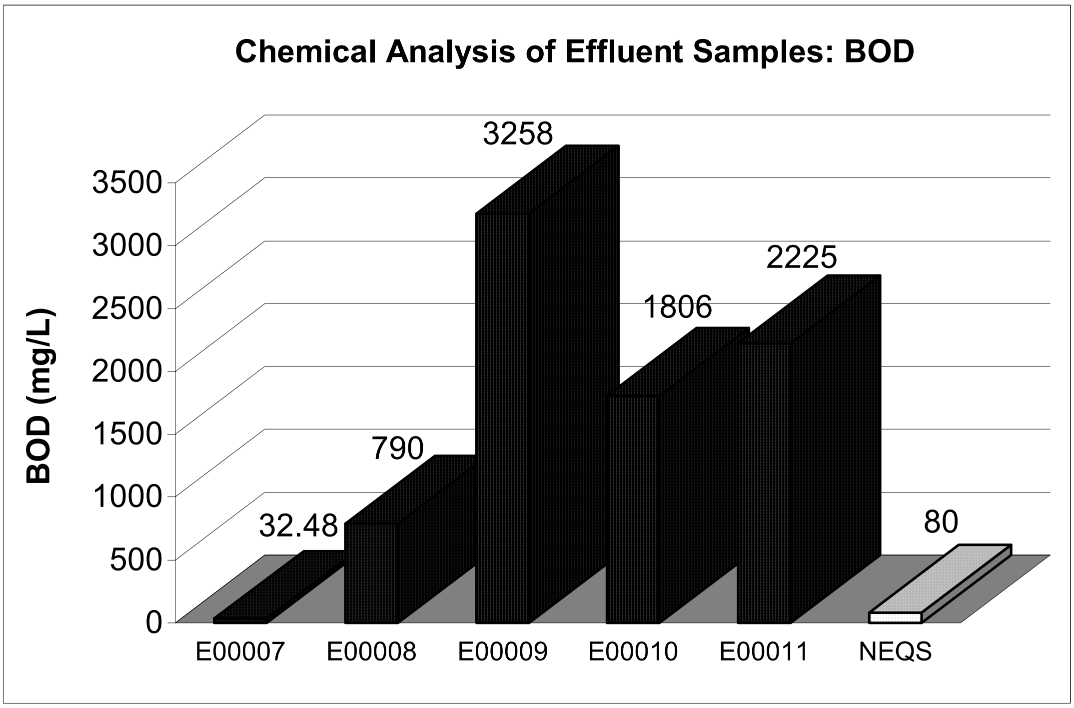
Source: *Monthly Environmental News,* July 2001

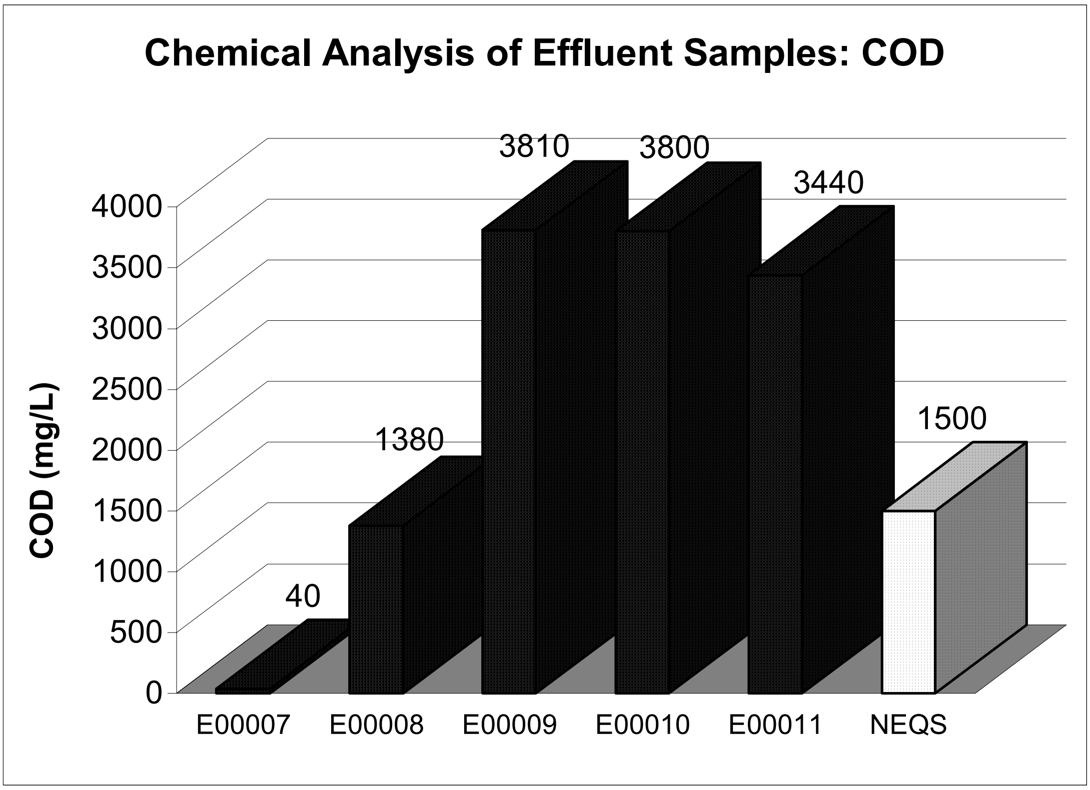
APPENDIX D: GRAPHIC PRESENTATIONS OF COMPARATIVE POLLUTANTS LEVELS IN EFFLUENTS SAMPLES FROM STUDIED SUGAR MILLS IN PAKISTAN



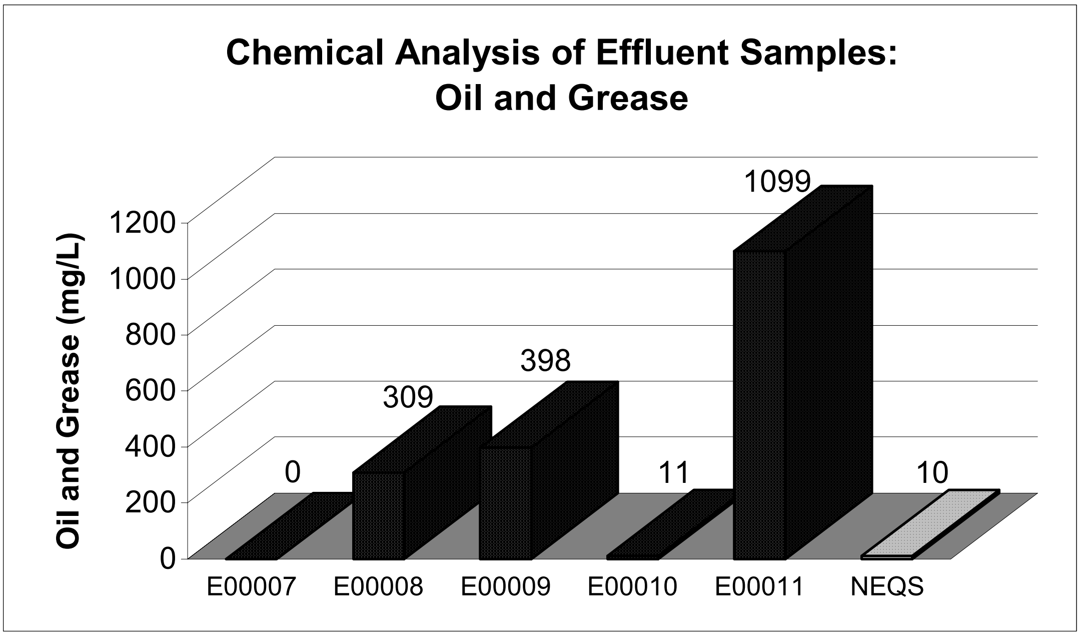



Chemical Analysis of Effluent Samples: TDS
TDS (mg/L)
8000
7000
6000
5000
4000
3000
2000
1000
0
1354
1914
7264
1962
2560
3500
E00007
E00008
E00009
E00010
E00011
NEQS

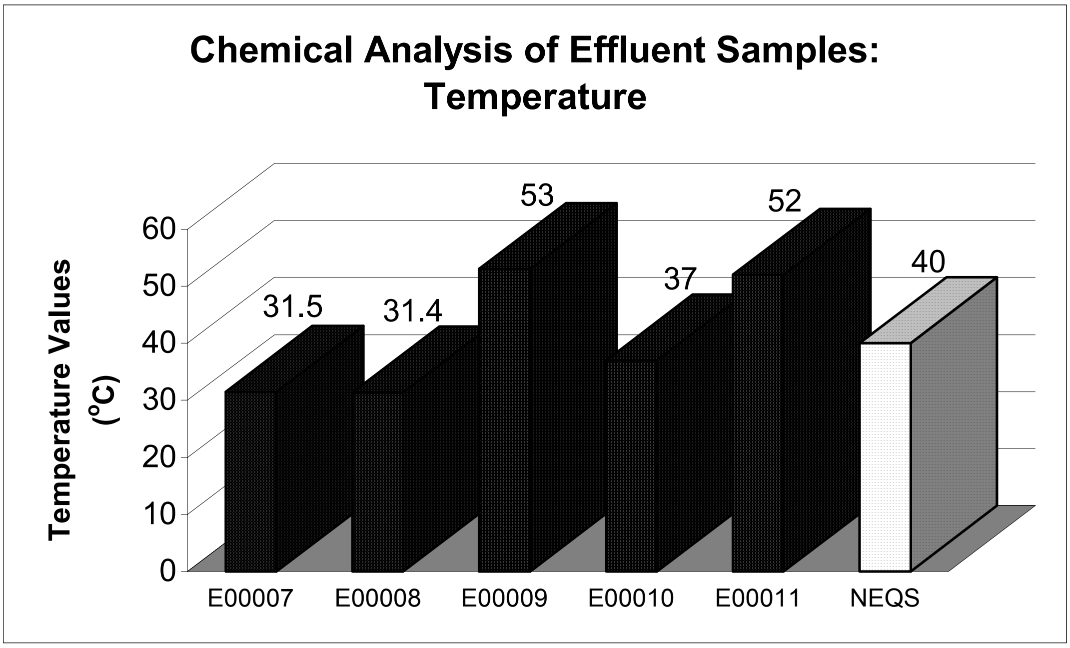

Chemical Analysis of Effluent Samples: BOD
BOD (mg/L)
3500
3000
2500
2000
1500
1000
500
0
32.48
790
3258
1806
2225
80
E00007
E00008
E00009
E00010
E00011
NEQS



Chemical Analysis of Effluent Samples: COD
COD (mg/L)
4000
3500
3000
2500
2000
1500
1000
500
0
40
1380
3810
3800
3440
1500
E00007
E00008
E00009
E00010
E00011
NEQS



Chemical Analysis of Effluent Samples:
Oil and Grease
Oil and Grease (mg/L)
1200
1000
800
600
400
200
0
0
309
398
11
1099
10
E00007
E00008
E00009
E00010
E00011
NEQS


Chemical Analysis of Effluent Samples:
Temperature
Temperature Values
(°C)
60
50
40
30
20
10
0
31.5
31.4
53
37
52
40
E00007
E00008
E00009
E00010
E00011
NEQS

APPENDIX E: FORMULA FOR POLLUTION CHARGE

$$\text{Pollution Charge (Rs.)} = \frac{(C-S) \times R \times D}{U \times 1000} \times F$$

Where:

C = pollutant concentration (mg/L) in effluent/emission
S = NEQS for the pollutant in consideration
R = flow rate (m^3/Day)
D = total number of operating days per year
U – pollution unit (kg) for pollutant in consideration
F = Fee (Rs.) per pollution unit

** Total payable pollution charge by an industry would be the sum total of pollution charges for all pollutants discharged in excess of NEQS*

Source: Khwaja, *Pollution Charge*, 2001

Appendix F: Comparison of Wastewater Treatment Technologies

Solutions	Technical Characteristics	Operational Characteristics
Lagoons	• Anerobic lagoons are deep earthen basins used for high strength organic wastewater with high solid concentration. • Facultative lagoons are earthen basins filled with screened or primary effluent in which stabilization of waste is brought about by a combination of aerobic, anaerobic and facultative bacteria. • Aerobic lagoons are l arge, shallow earthen basins used for treatment of wastewater by natural processes involving both algae and bacteria. • Maturation ponds are low rate stabilization ponds usually designed to provide for secondary effluent polishing and seasonal nitrification.	• BOD_5 loading kg/m3/d? least efficient • BOD_5 removal efficiency? 85 -90 % • Energy requirement for aeration kwh/kg BOD treated? moderately efficient • Hydraulic detention time? very high • Mechanical complexity? low • Reactor resilience for power failure and shock loads? moderate to high • By-product? nil • On-site environmental impacts - soil infiltration and aerosoles dispersion • Land requirement? large • Man power requirement? skilled • Frequency of repair & maintenance -medium
Trickling Filters	• Wastewater flows from top to bottom, dispersed over filter material (stones, lava or plastic) during which soluble compounds are removed and, to a lesser extent, solids are taken up into the biofilm adhered to the carrier material.	• BOD_5 loading kg/m3/d? least efficient • BOD_5 removal efficiency? 85 -90 % • Energy requirement for aeration kwh/kg BOD treated? most efficient (natural ventilation) • Hydraulic detention time? most efficient (recirculation is required)

		• Mechanical complexity? low • Reactor resilience for power failure and shock loads? moderate • By-product? nil • On-site environmental impacts - insects • Land requirement --- small • Man power requirement? skilled • Frequency of repair & maintenance -low
Upflow Anaerobic Sludge Blanket (UASB) Reactor	• The basic idea of this system is that the flocs of anaerobic bacteria will tend to settle under gravity, when applying a moderate up-flow velocity of water. In this way no separate sedimentation tank is necessary. • The wastewater passes the reactor from the bottom to top. To guarantee sufficient contact between the incoming wastewater and the bacteria in the sludge layer the wastewater is fed evenly over the bottom of the reactor. Further mixing is brought about by the production of the gas. • The organic compounds are consumed by anaerobic bacteria during passage of wastewater through the sludge layer and produces bio-gas.	• BOD_5 loading kg/m3/d? very efficient • BOD_5 removal efficiency? 80 -90 % • Energy requirement for aeration kwh/kg BOD treated? most efficient (only for pumping) • Hydraulic detention time? most efficient • Mechanical complexity? low • Reactor resilience for power failure and shock loads? moderate • By-product? bio -gas • On-site environmental impacts - nil • Land requirement --- small • Man power requirement? highly skilled • Frequency of repair & maintenance -low
Activated Sludge Treatment (Sequential Batch Reactor)	• Many variations of activated sludge treatment exist, depending on load characteristics. Sequential Batch Reactor most appropriate for high organic pollution loads. Most successfully applied if hourly flow is low. • System consists only of aeration tank (operated as fill and draw system) and mechanical surface aerators. Aeration and sedimentation takes place in the same reactor on the following cyclical principle: feeding and aeration of the reactor during a certain period, switch off of the aeration, followed by settling of the sludge and discharge of the effluent.	• BOD_5 loading kg/m3/d? very efficient • BOD_5 removal efficiency? 85 - 95 % • Energy requirement for aeration kwh/kg BOD treated? least efficient • Hydraulic detention time? moderately efficient • Mechanical complexity? high • Reactor resilience for power failure? low and for shock loads? moderate • By-product? nil • On-site environmental impacts - aerosol dispersion and noise

Source: *Monthly Environmental News,* July 2001