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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Pollution Prevention and Abatement Guidelines

for

Cane Sugar Processing and Refining

This document is one of the chapters prepared for a forthcoming set of poilution guidelines jointly prepared by the World Bank, UNIDO and UNEP. The purpose is to give a succinct overview of the main issues affecting the subject industry sector, and of the best technologies and techniques available to avoid undue environmental impact. The regulatory framework within which the industry operates is briefly described by examples, and target discharge limitations that are economically achievable with currently available technology are suggested. The intended readership includes project personnel in investment and development institutions as well as anyone who wish to familiarize themselves with the key aspects of the industry concerned. The information is not sufficient by itself for detailed project design. For this more elaborate advice can be obtained from the references quoted or from other specialized sources of information. Comments on the document should be submitted to Mr. Anil Somani, the World Bank, Environment Department, 1818 H Street N.W., Washington DC 20433, USA, fax. (202) 477-0968 with copy to UNIDO, Att. Mr. Ralph Luken, P.O. Box 300, A-1400 Vienna, Austria. Fax +43 1 23 07 449.

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US/GLO/91/202

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In 1991 the world sugar production amounted to approximately 114 million tons, of which 64% came from sugarcane and 36% from sugarbeet. There are more than 2200 sugar processing plants in 111 countries.

The report describes raw cane sugar processing and cane sugar refining and their respective impact on the environment. Generally, it is the effluent from the processing which is of major concern, although discharges to air, water and land occur in both operations. The residuals are generally putrescible organic materials.

Little more than 10% of the sugarcane can be processed into commercial sugar. Furthermore, for every ton of cane processed about twenty tons of water are needed. Thus, recycling and reuse of process water and residuals are very important both for the protection of the environment and for the overall profitability of operations. A well controlled and balanced production process with good sanitation which fully utilizes the possibilities for reusing residuals in the process or as by-products should be the starting point for environmental protection. In addition, treatment of water and air discharges is often necessary.

The United States New Source Performance Standards can serve as guidelines on achievable discharge limitations in the absence of national regulations. It is however important to consider factors such as: scale, age and location of plant; the assimilative capacity of the recipient medium during the crop season; and the time needed for plant upgrading (as preventive measures for pollution control are preferred it has to be recognized that these, in general, take more time to implement than end-of-pipe measures).

A considerable development of sucrochemistry and ethanol applications is expected in the near future. This development is expected to bring forth problems of pollution by aggressive molasses and vinasses on a much wider scale than previously associated with the sugar industry.

2 INTRODUCTION

Worldwide, sugarcane is cultivated between 30° latitude north and 30° latitude south. In 1991, the world sugar production amounted to approximately 114 million tons, of which 64% came from sugarcane and 36% from sugarbeet. There are more than 2200 sugar processing plants in 111 countries.

This report describes raw cane sugar processing and cane sugar refining and their respective impact on the environment. Generally, it is the waste from the processing which is of major concern, although residuals occur in both operations. Their potential and actual uses as by-products are important for both environmental and economic reasons.

The environmental concerns associated with sugar production include water and air pollution and the disposal of solid wastes. With proper management environmental impacts can be negligible. Wastes resulting from the processing and refining of sugar are generally putrescible organic materials which have potential for utilization and reuse.

3 MANUFACTURING PROCESSES

Although in a few cases raw cane sugar processing and cane sugar refining are carried out in the same plant, they are presented individually because the two operations present substantial differences and are most frequently carried out in separate locations.

3.1 RAW CANE SUGAR PROCESSING

Sugarcane has a variable composition, average figures are: 70% water; 14% fiber; 13.3% saccharose; and 2.7% soluble impurities. The processing of a ton of sugarcane yields on average between 105 and 115 kg of commercial sugar. The diagram below summarizes the processing of raw sugarcane to commercial sugar through the so called three boiling system:

Cane

Washing (if necessary) —>	separation of trash
Preparation —>	cut and shredded cane
Extraction —>	juice + bagasse
Clarification —>	clear juice + mud
Evaporation —>	syrup
Boiling (crystallization) —>	crystal + liquor
Mixing (crystallization) —>	crystals increase
Centrifugation —>	1st strike sugar + A molasses
A molasses recycling —>	2nd strike sugar + B molasses
B molasses recycling —>	3rd strike sugar + final molasses
Drying of crystallized sugar	
Storage —>	in bulk or in bags

V

Commercial Sugar

Figure 1 gives a schematic flow diagram for cane sugar processing.

Washing (or dry cleaning) is not always needed. The harvesting method used will appreciably affect the amounts of dirt, trash and mud entering a mill and decide if washing is necessary. After washing, the cane is cut into chips and shredded to enable the extraction of juice and bagasse. This is achieved by crushing in tandems of three roll mills, or diffusion system with diffuser and press or mills. The juice is separated from the cane fibrous residue called bagasse.

In the clarification stage impurities in the juice are removed through a process of screening, heating and liming. For the production of white plantation sugar, sulphur dioxide is added (sulphitation). Other supplementary treatments can be added such as phosphatation, carbonation, etc.. The juice is then decanted and the mud filtered.

The clarified juice is concentrated in multiple effect evaporators under reduced pressure, and a syrup is obtained. In the boiling stage a mixture of syrup, molasses and sugar remelt known as massecuite is further concentrated and partially crystallized in individual vacuum pans. Further crystallization is obtained in the mixing stage.

The sugar crystals are separated from the molasses in a series of centrifugations. The first centrifugation yields first strike sugar and A molasses. A molasses is again concentrated and centrifuged yielding second strike sugar and B molasses. B molasses is similarly concentrated and centrifuged yielding third strike sugar and final molasses. The third strike sugar is again melted and recycled in the first strike and/or used to initiate the strikes.

After centrifugation the sugar is dried and packed in bags or stored in bulk. White plantation sugar can be consumed in this state. Crude sugar is refined either in separate refineries or in the sugar plant itself with appropriate equipment.

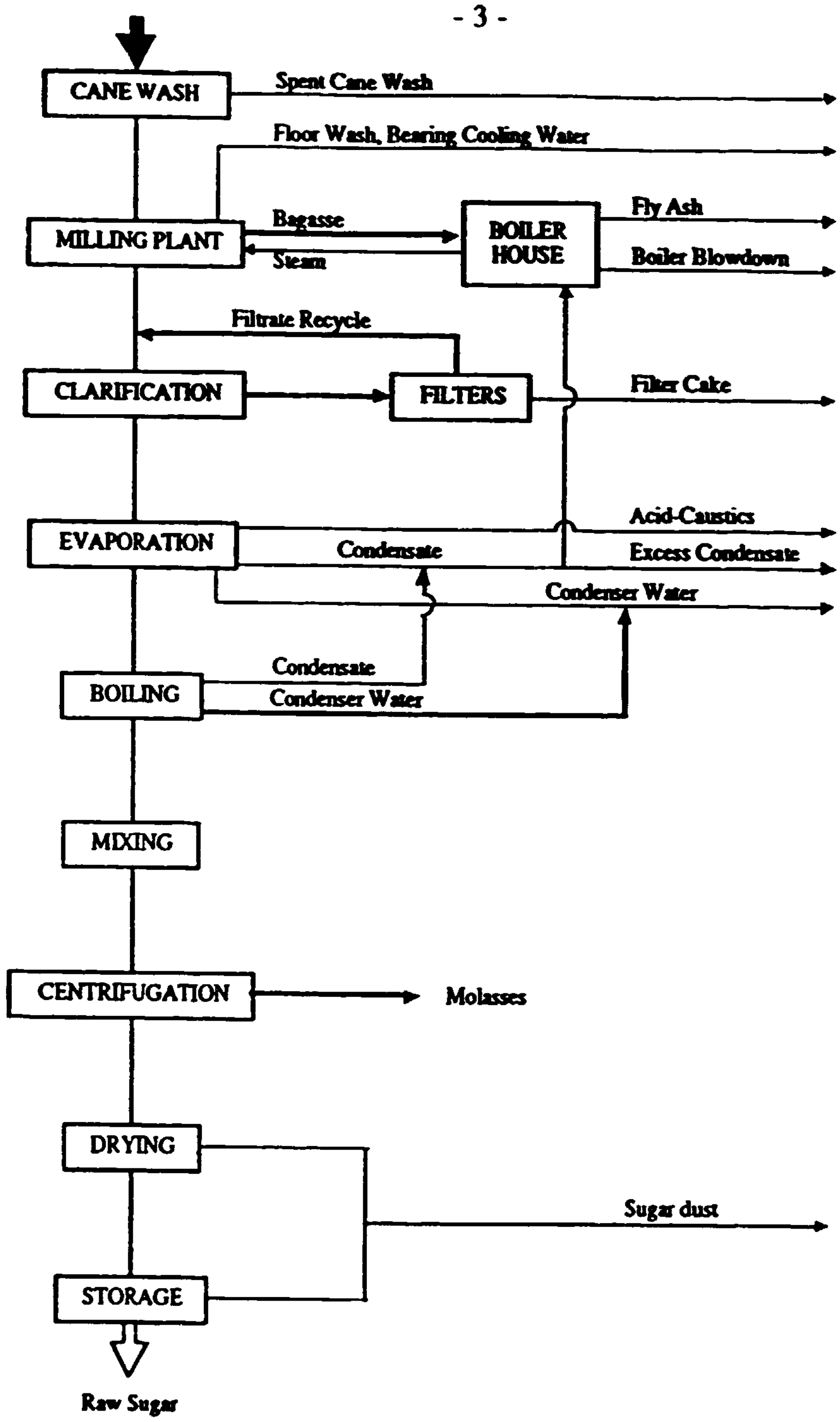

Figure 1. Schematic Flow Diagram for Cane Sugar Processing[1] (Ref. 11)

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[1] *Beet sugar manufacturing is similar to cane sugar processing from the point of clarification, only the washing, preparation and extraction processes differ. On arrival at the factory, the beet is analyzed for sugar content. After washing and weighing, the beet is sliced. The slices are drawn into a slowly rotating diffuser and treated with a counter current flow of water which separates the sugar from the beet slices. The juice is then treated by liming and carbonation (see cane sugar refining) after which clarification takes place.*

In terms of environmental impact a distinct feature of beet sugar processing is the large amount of water used in the early stages of the process. The resulting waste water requires settling and other treatments before it can be discharged. The fibrous residue needs attention as to its handling and re-use.

3.2 CANE SUGAR REFINING

The raw material for refining consists of the crystalline sugar produced by the raw cane sugar factories. The raw sugar contains a film of molasses, various impurities such as bagasse particles, organic and inorganic salts, and micro-organisms. Refining involves the removal of most of this film and the associated impurities. The steps generally followed include affination and melting, clarification, decolorization, evaporation, crystallization and finishing. A typical process flow diagram is presented in Figure 2. Processes will vary in detail from refinery to refinery. Such differences are particularly evident in decoloration methods, where the medium may consist of bone char, granular activated carbon, powdered activated carbon, vegetable carbon, ion-exchange resins or other materials.

The final product can either be liquid sugar or granulated sugar. Liquid sugar, is obtained by the same process as granulated sugar, except that crystallization and centrifugation are not carried out. Granulated sugar can be produced in various grades of crystal sizes and in cubes.

The following diagram summarizes the processing of raw sugar to commercial refined sugar:

```
Raw Sugar    Delivery
    |        Affination (mingling and
    |        centrifugation)----------->     affined sugar + affined syrup
    |        Boiling of affined syrup->      concentration
    |        Centrifugation------------>     recovered sugar + molasses
    |        Melting------------------->     melt of affined sugar - recovered sugar
    |        Clarification------------->     liming and carbonation
    |        Filtration---------------->     brown liquor + filter mud
    |        Decolorization------------>     char filtering or demineralization
    |        Evaporation--------------->     concentration in a multiple-effect system
    |        Boiling------------------->     Three or four strikes with molasses recycling
    |        Centrifugation------------>     refined sugar + final molasses
    |        Drying of refined sugar
    |        Cubing (if necessary)
    V        Packaging
Commercial
refined sugar
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The separation of the film of molasses from the surface of the raw sugar crystal involves mixing the raw sugar with warm syrup and then centrifuging in a process called affination. Water is used to wash the crystals and some sugar is removed with the impurities. This sugar is recovered by concentration and centrifugation.

The affined and the recovered sugar are melted together. The resulting liquor contains impurities which are removed through clarification. Clarification by carbonation consists basically of precipitating calcium carbonate in the melted liquor. This is achieved by adding lime and carbon dioxide gas under controlled conditions of temperature and alkalinity. Mud is separated from the clarified liquor through filtration under pressure in stationary or rotary leaf filters. Decolorization is the key process in refining. Decolorization is obtained by use of charcoal or resin or both. Liquid sugar is then obtained after concentration of the decolorized liquor in a multiple-effects evaporation system.

The sugar liquor is then crystallized through boiling and centrifugation in processes similar to those used in raw sugar factories. The concentration consists of boiling in individual vacuum pans and the separation of sugar and molasses is achieved by centrifugation with recycling of intermediate molasses.

The refined sugar crystals are dried in a current of warm clean air before being graded, molded into cubes or tablets if necessary, and packed.

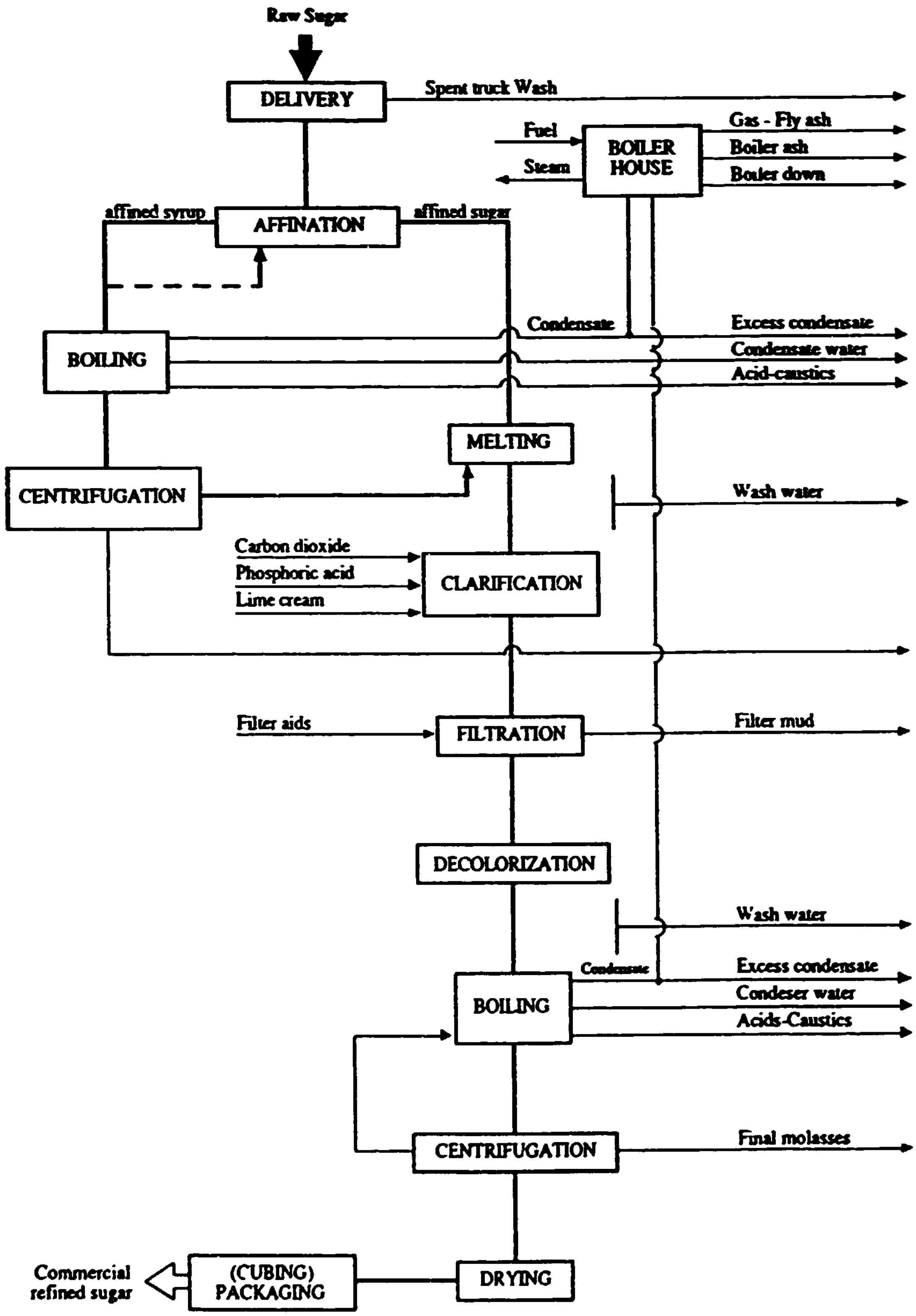

Figure 2. Schematic Flow Diagram for Sugar Refining

4 WASTE CHARACTERIZATION AND IMPACTS

The wastes associated with cane sugar processing and refining include water and air pollution and the disposal of solid wastes. The huge amount of biodegradable organic wastes from the processing is a major concern. The pollution load is therefore generally expressed in terms of biochemical oxygen demand (BOD_5) or chemical oxygen demand (COD) and suspended solids. The hydrogen ion concentration (pH) and the temperature are also important parameters in determining the polluting effects of wastes in sugar factories and refineries.

4.1 WASTE QUANTITIES AND QUALITIES

4.1.1 Atmospheric Emissions

The atmospheric pollution in the sugar processing and refining industry results mainly from the combustion of bagasse, fuel oil or coal. Examples of other processes giving small air emissions are: gases from juice fermentation; uncondensable gases from the evaporation stage; and sulphurous vapours released from the sulphitation process.

Bagasse combustion results in emissions of flue gas and fly ash. The composition of the flue gas depends on the composition of bagasse, its moisture and on the quantity of air used in combustion. A typical flue gas composition resulting from burning of bagasse is shown in Table 1.

Table 1. Bagasse Combustion - Composition of Flue Gas

Gas	Weight	Percent(%)
N_2	3.455	63.1
O_2	0.346	6.3
H_2O	0.784	14.3
CO_2	0.894	16.3
Total	5.479	100

Source: Bibliography 8

Assuming an average steam consumption of 550 kg/tc and 1 kg bagasse producing 2.25 kg of steam, the production of CO_2 would be 218 kg/tc[2].

The forced draught in modern boilers implies a large proportion of fly ash in the smoke. Boiler manufacturers estimate amounts to 5.5 kg of fly ash/tc or 4.5 g/m³ of fly ash in the smoke during bagasse combustion.

Refineries as well as some sugar processing plants (where the bagasse is used for other purposes) burn fuel oil or coal. This results in sulphur dioxide emissions (besides fly ash emissions) which can be high when using low-grade coal or oil with high sulphur content.

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[2]*Therefore, the whole cane sugar industry is responsible annually for the emission of 145 million tons of CO_2. However, since this CO_2 emission cannot be larger than the amount of CO_2 that the cane sugar plant absorbed during cultivation, the net addition of CO_2 to the atmosphere resulting from bagasse combustion would be zero.*

4.1.2 Waste Waters

The sugar industry is generally considered a large water consumer and polluter. However, the situation varies from country to country and inside countries as shown in Table 2.

Table 2. Effluent Characteristics of Various Cane Sugar Processing and Refining Waste Streams in Different Countries

Parameter	Puerto Rico	Hawai	Philippines	Lousiana	India
pH	5.3-8.8	-	5.3-7.9	-	6.8-8.4
BOD_5 (mg/l)	1[illegible]-225	115-699	130-1220	81-562	667-1660
COD (mg/l)	3[illegible]5-978	[illegible]42-2340	[illegible]0-1880	720-1430	890-2236
SS (mg/l)	1[illegible]-700	915-3590	240-5440	150-8120	504-936
TSS (mg/l)	50[illegible]-1400	[illegible]040-4500	-	409	792-2043
Temperature (C°)	[illegible]-49	-	34-48	-	-

Source: Bibliography 13

4.1.2.1 Raw Cane Sugar Processing

Water is essential in sugar processing, not only as a sugar solvent but also for many other uses in the process. It is used, for example, in: cane washing; extraction; liming; filter washing; crystallization; barometric condensers; cooling of engines and processing equipment; and for general purposes.

In modern sugar factories, water from vacuum condensers is recycled and a large part of condensed water from heat exchangers is recuperated for boiler feeding and other process uses. Older factories do not recycle the vacuum condenser waters and this creates a very large water throughput.

If Q is the quantity of cane processed, then the immediate need of water in a sugar processing plant would be approximately 20Q. This could be reduced to 0.9Q if all possibilities for recycling are employed, and to 1.3Q with partial recycling. Table 3 illustrates BOD_5 and COD values of the main waste water sources in a sugar factory, using partial recycling of process water.

Table 3: Example of Sugar Processing Plant Waste Waters Using Approximately 1.3 m^3 Water/tc.

Source	BOD_5 (mg/l)	COD (mg/l)
Cane washing	300 - 1500	450 - 8000
Condensate water	35 - 45	80 - 150
Barometric condensers	50 - 200	100 - 400
Filter mud slurry	2900 - 10000	6000 - 20000
Factory cleaning etc.	3000 - 5000	6000 - 10000

Source: Bibliography 11

Cane washing

In some cane-growing regions the cane, though still cut by hand, is loaded mechanically for transportation to the sugar factory. In this case field mud, trash and sometimes stones are brought along with the cane to the factory. All of this creates problems in milling, clarification, juice filtration and bagasse combustion. To resolve these difficulties, washing of the cane has been introduced in some countries. There are many variations and some installations are quite elaborate. Water coming from condensers is generally used for this purpose. The amount of mud removed by cane washing varies between 5 kg to 15 kg/tc. A disadvantage of cane washing is additional loss of sugar. When washed, the amount of sugar loss can reach 0.16% of the total weight of the sugar cane.

Water from barometric condensers

The vapours from the final evaporation stage and vacuum pans are condensed in barometric condensers. This condensation requires large amounts of water (18 tons of water/tc, with central barometric station), which gets mildly polluted, see Table 2. This waste water is characterized by high temperature (45°C), low oxygen content and the presence of sugar and gases (CO_2, NH_3) in solution. In the past, the waste water from the condensers was normally directly discharged. Today it is generally recycled to the condensers after passing through an atmospheric cooler.

The water from barometric condensers of vacuum mud filters has a considerable sugar content, but, as it cannot be recycled, must be discharged.

Condensate water

The first stages of evaporation also generate condensate water. Some of this (all from the first and some from the second effect) is used as feeding water for the boilers. Condensate from heaters cannot be used for this purpose because it may contain juice in case of a tube failure in the heater.

The remainder of the condensates has various uses in the process (milling, liming, cake filter washing, crystallization: melting, clearing, vacuum pan washing, heating of the massecuite etc.). The excess is generally discharged. It is characterized by high temperature (80°C), low oxygen content and the presence of sugar and gases (CO_2, NH_3) in solution.

Cooling water for engines

Cooling of turbo-machines requires very clean and demineralized water which can also be used for cooling pumps, compressors and crystallizers. The cooling water for the mill roller bearings becomes charged with oil and is generally discharged.

Water for general purposes

The water used for cleaning of the factory becomes highly polluted. There are three main sources of contamination:

1) Fermentation of juice: this occurs mainly in the preparation, extraction and clarification stages of the process.
2) Mechanical sugar losses: overflows, leaking pumps etc.
3) Cleaning of calorific exchangers: chemical cleaning with corrosive products such as sulphuric acid and soda implies a discharge of polluted and corrosive water after washing.

4.1.2.2 Cane Sugar Refining

Waste water discharges may originate from condensers, filter backwash, truck and equipment washing, floor drains, boiler feed blowdown, engine cooling, floor washing and other miscellaneous processes. The pollutants are primarily:

1) Insoluble suspended solids: mostly water slurries of calcium carbonate or phosphate salts, diatomaceous earth, spent charcoal of carbon etc..
2) Dissolved waste consisting primarily of biodegradable carbohydrates.

The average BOD_5 content in refinery waste water is about 1000 to 2000 mg/liter. Volumes of effluent range typically between 18 to 25 m^3 water per ton of sugar.

Table 4: Example of Refinery Waste Waters

Source	BOD_5 (mg O_2/l)	COD (mg O_2/l)
Condenser waters	4 -21	6 - 42
Filter mud slurry	~30	1200 - 1400
Char waste	750 - 1200	1200 - 2400
Truck wash water	15000 - 18000	22000 - 36000

Source: Bibliography 11

4.2 FUGITIVE EMISSIONS

Small, fugitive emissions result from juice fermentation; uncondensable gases from the evaporation stage; and sulphurous vapours released from the sulphitation process.

4.3 UPSET AND EMERGENCY CONDITIONS

The storage of raw bagasse is a problem due to the large volumes involved and its low time of preservation. A considerable storage area is required and the rapid degradation cause a risk for internal combustion after a few months of storage only.

4.4 IMPACT ON RECEPTORS

Most waste waters from sugar processing and refining is not toxic yet harmful to the environment at higher levels of biological oxygen demand. This is due to the carbohydrate content and the products of their degradation. Organic substances discharged into water (rivers, lakes) are decomposed by microorganisms which use large quantities of oxygen. The resulting lack of dissolved oxygen affects the breeding of fish and the ecological equilibrium of the receiving medium. Waste water from sugar processing also contain oil solids, caustic and acid. All of these products cause severe non-biological contamination of receiving waters.

On land, the use of residual water or by-products for irrigation must be strictly controlled and used according to the requirements of the crop and the soil, and not as a means of waste disposal. The high Chemical Oxygen Demand·Nitrogen content (COD/N) ratio does not allow an intensive application during the first stages of cane development.

5 POLLUTION PREVENTION AND CONTROL

5.1 MANAGEMENT IMPLICATIONS

A considerable development of sucrochemistry and ethanol applications is expected in the near future. This development will bring forth problems on a scale, especially associated with pollution by aggressive molasses and vinasses, that make current problems appear insignificant. To counteract, suitable national strategies for environmental protection in the sugar sector must be developed.

Such strategies must consider the current situation of the sugar sector, its achievements and difficulties and its future development. If a national Master Plan for the restructuring, strengthening and development of the sugar sector exists, it is a good base on which to formulate a comprehensive environmental protection strategy. Issues to consider include:

- How to establish a step-wise approach that is suitable for the current situation as well as future developments? Environmental protection is as much a problem of attitudes as of investment capital. Acquisition of knowledge and training takes time. It took developed countries more than 20 years to modify attitudes concerning pollution problems so as to obtain a wide consensus that action was needed.
- What legal dispositions and control means must be set up? What encouraging measures and aids are needed? What penalties should be imposed in case of regulations being violated?
- How to ensure full and close cooperation between government authorities, sugar institutions and sugar producers, and how to provide them with adequate training and necessary laboratory equipment and facilities?

Immediate improvements of the environmental performance are possible at the plant level. Sugar producers must be made aware that a well-controlled and balanced factory with good sanitation is the most effective way to prevent pollution. Furthermore, the possibilities for reusing wastes in the process or as by-products are rarely fully exploited. Once this awareness is established two actions which assist them in achieving a higher level of environmental performance are:

- a corporate environmental policy that gives clear goals, responsibilities, actions and targets
- establishment of a proper environmental management structure to ensure implementation of the policy, to allocate resources, and to monitor (and report) the results.

5.2 SOURCE REDUCTION

Cane sugar processing and refining offer many waste minimization opportunities through reduction of wastes at the source, or, reuse in the process or as by-products.

Atmospheric emissions due to uncondensable gases can be decreased by using good sanitation and careful control of the whole operation. Flue gas emissions can be reduced by controlling combustion, air pressure and the rate of excess air.

The sulphitation clarification process is used in many sugar factories for the production of "white plantation sugar". This process, associated with a high pollution load, has been replaced increasingly by other methods, such as: Talo-floc[3] process; uses of bentonite; double centrifugation; and affination etc..

It is important that the cane is processed as soon it arrives at the plant to avoid deterioration with resulting sugar losses and odour problems. Immediate processing will also reduce the storage area needed. Dry cleaning systems which reduce or replace cane washing will result in reduced amounts of sludge.

If the production of slurries is unavoidable, in several cases contamination can be greatly reduced by means of such precautions as:

- Elimination of refuse, pieces of cane stalk and suspended dirt from the used wash water by screening before lagooning. This precaution allows decreasing the BOD load.
- Maintaining absolute cleanliness at all stations.

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[3] *Registered trademark*

- Avoiding fermentation of sugar-cane juices by: appropriate straining; proper sanitation of the mills; controlled application of disinfectants or biocides in mill juices; and systematic cleaning when the milling has stopped.
- Investigation of abnormal sugar losses in order to find and rectify the cause.
- Calculation of the general water balance of the factory for each crop.
- Maintaining a systematic control not only of boiler feeding water but also of the waste water.
- Periodic inspection and BOD control of lagoons.

A significant source of waste water loading is due to poor housekeeping practices, involving spills of sugar and molasses, and poor maintenance of machinery and equipment, which also contribute to oil and grease contamination of effluent. The cost of effective in-plant control is negligible when compared to the costs of effluent treatment and production losses.

5.3 RECYCLING AND/OR BY-PRODUCT RECOVERY

Little more than 10% of the sugarcane can be processed into commercial sugar. Furthermore, for every ton of cane processed about twenty tons of water is needed. Thus, recycling and reuse of process water and residuals are very important both for the protection of the environment and for the overall profitability of operations.

5.3.1 Waste Segregation

Establishing good water management with as much recycling of process water as possible is essential. The segregation of waste streams with a low BOD load from streams with a high BOD load is vital in this context. Few sugar factories and refineries segregate waste streams in a systematic way. Examples of the potential of this approach are:

- Excess condensate water does not need any treatment because of its low pollution load and can be separated from other streams, see Tables 2 and 3.
- In sugar factories where cane washing is practiced, the spent water is generally treated by impounding and recycled to the initial wash. This circuit has to be separated from other treatment circuits because the retention time is different. Fresh water is only used for the final wash.
- Cooling water for mill bearings contains mineral oils and should not be mixed with other waste streams destined for biological treatment without a previous passage through an oil separator (which is a very simple factory-made device). With an efficient oil separation, this water can be recycled.
- In both sugar factories and refineries, acid and caustic waste arise from the cleaning of heat exchangers, evaporators, pans and other equipment. These wastes must be kept separated from other wastes, stored and released gradually into furrows, and blended with general effluent.
- In refineries, the main water pollution load comes from washing trucks and floors. Two waste water circuits are sufficient, one for excess condensate water which needs no treatment and another for treating the wash water.
- Vacuum condenser streams are too large for economical treatment. Entrainment channels should be installed to prevent any contamination of this waste stream.
- Concentrate low volume streams can be biologically treated in lagoons or aerobically in an activated sludge plant.

5.3.2 By-Products

In almost all sugar factories and refineries, by-products are recovered for industrial use, for animal feeding and for fertilizing[4].

5.3.2.1 Boiler ash and fly ash

Boiler ash and fly ash can be used in glass manufacturing, as a basic fertilizer in agriculture and incorporated in slag cement and road bases. The average quantity produced is about 0.3% of the weight of cane[5].

Another possibility is to use recovered fly ash in place of bagacillo in vacuum filters. The density and composition of fly ash and the dimension of particles would produce an excellent filter cake. The need of bagacillo for filters is about 6 kg/tc at 49% moisture, equivalent to 4 kg/tc of fly ash which is more dry. Available quantities of fly ash (5.1 kg/t.c) adequately fulfill these requirements. The arrangement is very simple and inexpensive and consists of a mixing tanker and a slush pump. This is particularly interesting for those cane sugar plants which are short of bagacillo.

5.3.2.2 Bagasse

1000 kg of cane produces some 250/300 kg of bagasse, consisting on average of 49% water, 48.5% fiber and 2.5% of dry matters (sucrose and non sucrose). Most of it is used to generate the steam and energy required by the factory. Surplus bagasse, due to its low density (160 kg/m^3) and relative inflammability, is a cumbersome material to handle and transport. It is generally used to produce paper, board and electricity.

5.3.2.3 Filter mud

About 30-35 kg of filter mud are produced per ton of cane. Filter mud consists of 80% water and 0.9 to 1.5% sugar. It can be spread directly on agricultural fields or stored in an intermediary silo for later use as a soil conditioner. When used for this purpose care must be taken to avoid runoff to watercourses; filter mud has a large BOD load.

5.3.2.4 Molasses

Between 27 kg to 40 kg (average 30 kg) of molasses are produced per ton of cane. Its average composition is 20 % water, 35% sucrose, 20% reducing sugar, 15% sulphated ash and 10% others. Molasses is mainly used as animal feed or transformed into rum, alcohol or ethanol by fermentation and distillation.

In the distillery, 1000 kg of molasses give 400 l of pure alcohol (240 kg) and 380 l of stillage (also called slop or vinasses). Direct distillation of 1000 kg of cane juice yields approximately 70 l of pure alcohol and 910 l of vinasses. Vinasses are often sent to the cane field as fertilizer, either pumped to neighbouring fields or carried to more remote fields in motor tankers. This practice constitutes a major risk for the environment and especially contamination of ground waters if not adequately controlled by agronomists.

The use of dilute molasses and vinasses as fertilizers is much more complicated than, for example, the use of ashes and filter mud for such purposes. Successful fertilization with molasses and

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[4]*Only the main uses are indicated here. Over 150 uses of sugarcane by-products are known (J.M. Patureau - The State of the Art in the Utilization of By-Products of the Cane Sugar Industry. ISCTT Jakarta 1987).*

[5]*i.e. 1000 t of bagasse ashes for a factory handling 300.000 t of cane. 1 t of ashes gives some 21 kg of CaO, 8 kg of MgO, 3 kg of P_2O_5 and 15 kg of K_2O.*

vinasses must consider the demand of the cane plant which differs with variety, age, soil, climatic condition and season. Furthermore, the retention time needed for the release of the fertilizing elements from the by-product has to be considered in relation to the permeability of the soil.

5.3.2.5 Irrigation with Residuals

The residual water from cane sugar operations has a high content of organic matter and nutrients and is thus considered a valuable biofertilizer. In countries where water is scarce cane sugar effluent can be used for irrigation. With strict control and norms of application it can be considered the most practicable technology. In Cuba, irrigation with residual water has been systematically used with the following modes of application (bibliography 9):

- Outflows with high dissolved salt content, particularly sodium, and acidic effluent must be separated from the water used for irrigation. Examples of such effluents are exhausted soda, overflow from the coolers when soda has been used to raise the pH and acidic cleaning water.
- After preliminary treatment to remove oil and suspended matters and correction of pH, the residues are cooled and homogenized before being applied to the soil. A storage system with two reservoirs designed for the total volume of residual water from the sugar factory is used. In the first reservoir the water remains for one or two days, giving time for homogenization and cooling but without allowing degradation of the organic matter. The second reservoir is only for preventing the water from spilling into a watercourse, when steady irrigation is not possible.
- One year of effluent irrigation must be followed by one year of normal irrigation for light soils (two year periods for heavy soils), and in both cases using standards that do not exceed 300 to 400 m^3/hectare at intervals of 10 to 15 days.
- The salt level in the soil subject to irrigation with cane sugar effluent must be checked periodically.
- Where necessary grease and oil traps are installed and cleaned periodically.
- Due to the high Carbon/Nitrogen (C/N) ratio in this type of water, irrigation must not be applied intensively during the first stages of crop development, when plants require more nitrogen. It might be necessary to add a nitrogen fertilizer.

Actual investment, operating and maintenance costs, and savings for a cane sugar effluent irrigation system, compiled in Table 5, is based upon experiences from Cuba.

Table 5. Cost and Benefits of an Effluent Irrigation System of a 6,800 tc/day Sugar Factory in Cuba. (1991 US$)

Technology	Investment (US$)	Maintenance and operating cost (US$/1000$m^3$ effluent)	Savings (US$/1000$m^3$ effluent)
Irrigation system	297,000	59.24	40.76

The plant in question produces about 0.55 m^3 effluent for every ton of milled cane or 560,000 m^3 per crop season. The pay-back period for the investment is thus approximately 13 crop seasons. 188 hectares are irrigated.

Source: Bibliography 9

5.4 ADD-ON TREATMENT TECHNOLOGIES

5.4.1 Atmospheric Emission Control

The major air emission is suspended particles from boilers. These can be removed from the exhaust stream by use of centrifugal collectors, fabric filters (baghouses), electrostatic precipitators and wet scrubbers.

Wet scrubbing is the most commonly used air pollution control technology in sugar cane factories. The fumes enter a chamber in which water is sprayed. The wet cinders drop and are driven out by a water flow. Another method (the Modave system) involves cast iron columns of triangular section along which water runs. The efficiency of wet scrubbers is as high as 95-96%. Water consumption is 0.4 to 0.5 m^3 for 1000 m^3 of fumes. Well-managed wet scrubbers can be very efficient, but they do not remove the smallest particles which can be scattered as far as 20 km from the factory.

Centrifugal collectors are used for removing particulate and for drawing air through the boiler. They can be of simple-cyclones or multi-cyclones type (efficiency 75% and up to 96% respectively); in the last case the rate of dust can be decreased until 500 mg/m^3.

There are various designs of electrostatic precipitators. They act by ionizing the dust particles in the gas stream and pulling them in an electrostatic field towards an electrode which is periodically cleared. The efficiency can be very high, but the equipment is voluminous and expensive.

5.4.2 Waste Water Treatment

In raw cane sugar factories, treatment, when existent, is often of a rudimentary nature, consisting in the impoundment of all contaminated water with eventual recycling of cane wash water. As ponds generally have not been designed with accuracy and are not controlled, the results obtained are unpredictable.

Cane sugar refineries have more often a controlled effluent treatment. Current practices include impoundment systems, sometimes with double lagooning and disposal of process waters into municipal sewers.

5.4.2.1 Lagooning System

When land is readily available, the double or triple lagooning systems are considered the best and most economic technological solutions (BPTEA). They are both well adapted to the average pollution load of process waters from cane sugar factories and refineries.

The double lagooning system consists of an initial anaerobic lagoon (depth: 2.5 to 3 m), followed by a second, aerobic lagoon (depth: 0.8 to 1 m). The retention time and the surface covered must be calculated separately considering the difference between the two modes of bacterial behaviour. BOD reduction is about 70% in a double lagooning system.

In China, most sugar mills which burn coal remove the furnace cinder by high pressure water jet. This effluent, together with the water used when removing fly ash from the flue gas, is treated in two stages. The effluent is first mixed with a coagulant and solids settle in the first pond where coarse sludge is removed. The clarified water then enters the second pond to remove the fine particles. The treated waste water meets the demand of the national effluent standard. The coarse sludge contains a certain amount of unburnt coal, which can be reused. Usually the recovered coal will cover the cost of the coagulant.

In Louisiana, USA, the spent cane wash water is settled, after filtration, in a clarifier and sent to a simple or double lagoon.

The advantages of lagooning systems are low capital investment and insignificant operating and maintenance costs. The major inconveniences are the large areas required, the eventual danger of subsoil contamination and the production of undesirable odours during the anaerobic putrefaction phases. With properly designed ponds the last two disadvantages disappear.

5.4.2.2 Aerobic Fermentation for Concentrate Waste Streams

Various processes are used deriving from the clarification of sludge waters in beet sugar factories. In the Eimco-Process a clarifier is used with the introduction of oxygen by surface aerators. The clarification and treatment require 2 hours within which BOD is reduced by 40-60%.

In the R.T. Lefrancois Process the clarification is preceded by a fermentation stage. Oxygen is introduced at the bottom of the fermentor as compressed air. The air achieves also a systematic circulation and agitation of the mixed liquor in the fermentor. The process is suitable for a heavy pollution load (BOD_5 up 5.000 mgO_2/l) and can accomplish 90% BOD_5 reduction. It is characterized by: high concentration of activated sludge (SS 11 to 16 g/l); retention time: 4 h; energy consumption: 0.6 kwh/kg BOD_5.

5.4.2.3 Anaerobic Treatment

The advantage of anaerobic treatment is the production of methane by methanobacteria through the stages of hydrolysis, acidification, acetogenesis and methanogenesis. Basic industrial applications are: fermentor with mechanical agitator; fermentor with sludge expanded bed; fermentor with fixed bacteria film; and the upflow anaerobic sludge blanket.

5.4.2.4 Finishing Systems

To meet effluent standards that are stricter than normal, due to, for example, vicinity of urban center, sugar factories or refineries may have to use more than one treatment process. The most often used finishing systems are:

- aerobic lagooning: retention time is about 8 to 12 days. Oxygenation can be done by aerators or air dispersing turbines.
- oxidation ditch with surface aerators
- bacteriological filters.

5.4.2.5 Capital, Operating and Maintenance Costs

Estimated capital, operating and maintenance costs for effluent treatment technologies are compiled in Table 6.

Table 6. Capital, Operating and Maintenance Costs for Cane Sugar Effluent Treatment (1991, US$).

Treatment Technology	Investment (US$)	Maintenance and operating cost (% of total plant operating cost)
Natural lagooning for 3000 tc/day factory	120,000[a]	Insignificant
Double lagooning for 3000 tc/day factory	200,000[b]	0.3%
Aerobic clarifier for 3000 tc/day factory	700,000	0.8-1.4%
Anaerobic treatment for 30 ton COD/day (28 kg COD/m^3)	2,000,000[c]	2%

[a]Including pumps and civil works.
[b]Including aerators
[c]Digester and annexes = 1,100,000 US$
Civil works and utilities = 700,000 US$
Gas circuit etc. = 200,000 US$

For other capacities than those mentioned the equation $P=P_i(C/C_i)^{0.65}$ can be used, in which: P=investment cost to be determined; P_i=indicated cost; C=capacity of the installation; and C_i=indicated capacity.

Source: Information communicated to the author

6 OCCUPATIONAL HEALTH AND SAFETY ISSUES

Some years ago, sugar was thought to be a cause of degenerative diseases such as atheroma, coronary heart disease and diabetes mellitus. Except in the case of dental caries, the evidence for such connections is disputed.

There are few health problems associated with cane sugar processing and refining. The major hazards include bagassosis from handling dry bagasse and inhalation of sulphur dioxide at the sulphitation station (if in use). Both affect few people and can be limited by using a textile mask placed over the nose and mouth. Persons working in bagasse stations and on sulphur furnaces should receive regular medical examinations.

Some precautions should also be taken in sugar drying areas and at storage and packaging stations. The use of protective masks is recommended, and smoking must be prohibited as sugar dust is highly explosive. Fly ash from bagasse fired boilers can also be a severe airborne irritant.

7 GLOBAL OVERVIEW OF DISCHARGE GUIDELINES

7.1 NORTH AMERICA

Under the Federal Water Pollution Control Act Amendments of 1972, the US Environmental Protection Agency issued effluent guidelines and standards for the sugar processing point source category. These cover raw cane sugar processing in several different areas (Louisiana, Florida, Texas, Hawaii and Puerto Rico), as well as crystalline cane sugar refining and liquid cane sugar refining.

The effluent limitations for the State of Louisiana are given as an example of those for raw cane sugar. They represent the degree of effluent reduction attainable by the application of the "best practicable control technology currently available" (BPT), and are given separately for the continuous discharge of waste waters and for factories using waste stabilization.

For crystalline cane sugar refining, effluent limitations for existing refineries are given both for BPT and for the "best available technology economically achievable" (BAT).

Table 7 Effluent Limitations for Raw Cane Sugar Processing (Louisiana, USA)

Parameter	Continuous discharge: Maximum for any one day (kg/ton of cane)	Continuous discharge: Maximum average of daily values for 30 consecutive days (kg/ton of cane)	Waste stabilization: Maximum of daily values for entire discharge period (kg/ton of cane)
BOD_5[a]	1.14	0.63	0.63
TSS[b]	1.14	0.47	0.47

[a]For barometric condenser cooling water together with treated process waste water.
[b] For treated process waste water only.

Source: Bibliography 16.

Table 8 Effluent limitations for existing crystalline cane sugar refineries (USA)

Parameter	Maximum for any one day (kg/ton of melt)		Maximum average of daily values for 30 consecutive days (kg/ton of melt)	
	BPT	BAT	BPT	BAT
BOD_5	1.19 (1.02)[a]	0.18	0.43 (0.32)[a]	0.09
TSS	0.27[b]	0.11	0.19[b]	0.035

[a]For barometric condenser cooling water together with treated process waste water.
[b] For treated process waste water only.

Source: Bibliography 16.

Table 9 Effluent limitations for existing liquid cane sugar refineries in the USA.

Parameter	Maximum for any one day (kg/ton of melt)		Maximum average of daily values for 30 consecutive days (kg/ton of melt)	
	BPT	BAT	BPT	BAT
BOD_5	0.78 (0.45)[a]	0.3	0.32 (0.15)[a]	0.15
TSS	0.50[b]	0.09	0.17[b]	0.03

[a]Applies to refineries discharging barometric condenser cooling water only.
[b]No limitation imposed on refineries discharging barometric condenser cooling water only.

Source: Bibliography 16.

7.2 OECD COUNTRIES

Except in south of Spain, there are no cane sugar factories in OECD countries. For sugar refineries, the effluent limitations are different for each OECD country.

The OECD legislation introduces the notion of industrial waste waters similar to urban waste effluent for all agro-food industries. It contains the following effluent standards:

- BOD,: 25 mg/l or 70 to 90% reduction
- COD: 100 mg/l or 75% reduction
- SS: 30 mg/l

7.3 DEVELOPING COUNTRIES

Legislation varies from one country to another. The main problem is not the standards but the enforcement of them. This problem is accentuated when sugar factories are isolated and far from urban centres.

In China the maximum allowed concentration of effluent discharges is dependent on the raw material (cane or beet), the age of the plant (new or old) and the location of the province. The effluent limitations are expressed in concentration for a given volume of waste water per ton of raw material.

Table 10 National Integrated Control Standard in China. Maximum Allowed Concentration of Sewage Discharges

Type of production	Old or New/ reconstructed plant	Maximum volume of waste water allowed	Maximum allowed concent(mg/l) of sewage discharges					
			BOD,		COD		Soluble Solids	
			Class		Class		Class	
			I	II	I	II	I	II
Cane sugar factory	New	10m³/t cane		100		160		150
	Old	14m³/t cane	100	120	160	200	150	200
Beet sugar factory	New	4m³/t beet		140		250		200
	Old	6m³/t beet	150	250	250	400	200	300
Alcohol from molasses	New	70m³/t alcohol		200		350		200
	Old	80m³/t alcohol	200	300	350	450	200	300

Source: Bibliography 2. (GB89 78-88 UDC 628.391 628.54).

Table 11: Integrated Control Standard of Guangdong Province. Maximum Allowed Concentrations of Sewage Discharges

Type of production	Old or new/ reconstructed plant	Maximum volume of waste water allowed	Maximum allowed concentration of sewage discharges (mg/l)					
			BOD_5		COD		Soluble Solids	
			Class		Class		Class	
			II&III	IV	II&III	IV	II&III	IV
Cane sugar factory	unclassified	17m³/t cane			100	120		
Alcohol and other products from molasses	unclassified	70m³/t alcohol 600m³/t gourmet powder	150	200	300	350		
Alcohol and other products from molasses	New	70m³/t alcohol		200		350		200
	Old	80m³/t alcohol	200	300	350	450	200	300

Source: Bibliography 2, (DB44 26-8)

In India and Taiwan, discharge standards for sugar industries are as described in Table 12.

Table 12: Discharge Standards for Sugar Industries in India and Taiwan

Parameter	India	Taiwan
BOD mg/l	100[a] (30[b])	80
TSS mg/l	100[a] (30[b])	200
COD mg/l	-	300

[a] Disposal on land
[b] Discharge in surface waters

Sources: Environmental Protection Rule. Ministry of Environment and Forests. 1986; and Effluent standards under Water Pollution Control Law, section 9.2 - Environmental Protection Laws in Taiwan. 1991.

8 TARGET/PREFERRED GUIDELINES

For developing and developed countries alike the USA NSPS standards can be recommended as target/preferred guidelines, see Tables 7, 8 and 9 respectively. It is however of utmost importance, especially in developing countries, to adopt a degree of regulatory flexibility and consider factors such as:

- scale, age and location of plant
- the assimilative capacity of the recipient medium during the crop season. The USA NSPS standards do not consider the recipient medium.
- the time needed for plant upgrading. As preventive measures for pollution control are preferred it has to be recognized that these, in general, take more time to implement than end-of-pipe measures.

9 MONITORING REQUIREMENTS

Monitoring of COD and SS content of the effluent can and should be checked in every factory. It requires a minimum of training of laboratory personnel.

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