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OPTIONS FOR HANDLING STILLAGE WASTE FROM SUGAR-BASED FUEL ETHANOL PRODUCTION

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ABSTRACT

While the stillage waste from ethanol fuel production can be a serious source of water pollution, it can also be a valuable resource from which to recover useful products such as fertilizer, animal feed, or methane gas. Selecting the most appropriate stillage management is a matter of trade-offs between energy, economic, and environmental considerations. There is a need for an information clearing-house on commercial stillage handling processes to assist ethanol fuel developers in matching processes to their needs.

INTRODUCTION

Many countries throughout the world are seriously looking for ways to reduce their petroleum imports because of recent spirals in petroleum prices. They are looking toward alternative sources of energy that can be produced locally. Many of the new liquid fuel technologies, however, will require massive capital investments and long lead times before they are in large-scale production. In contrast, fermentation distilleries for ethanol can go into immediate production. With the technology already well proven, the distilleries can use a variety of feedstocks (sugars and starches) that can be produced almost anywhere in the world.

Figure 1 shows some of the issues concerning large-scale alcohol fuel development [1]. The basic policy question at the top of the diagram is entwined with issues and management questions that arise proceeding downward in the diagram. Many of the issues revolve around the question of what land will be used to grow the feedstock, economic competitiveness of alcohol with petroleum, or the need for an assured domestic source of liquid fuel even if it is not fully competitive. There is, however, also the issue of liquid stillage waste produced as a by-product of the fermentation—distillation process and what should be done with it.

A distillery produces about 13 liters of stillage for every liter of alcohol [2]. A typical large distillery, which produces 150 m^3/day of ethanol, there-

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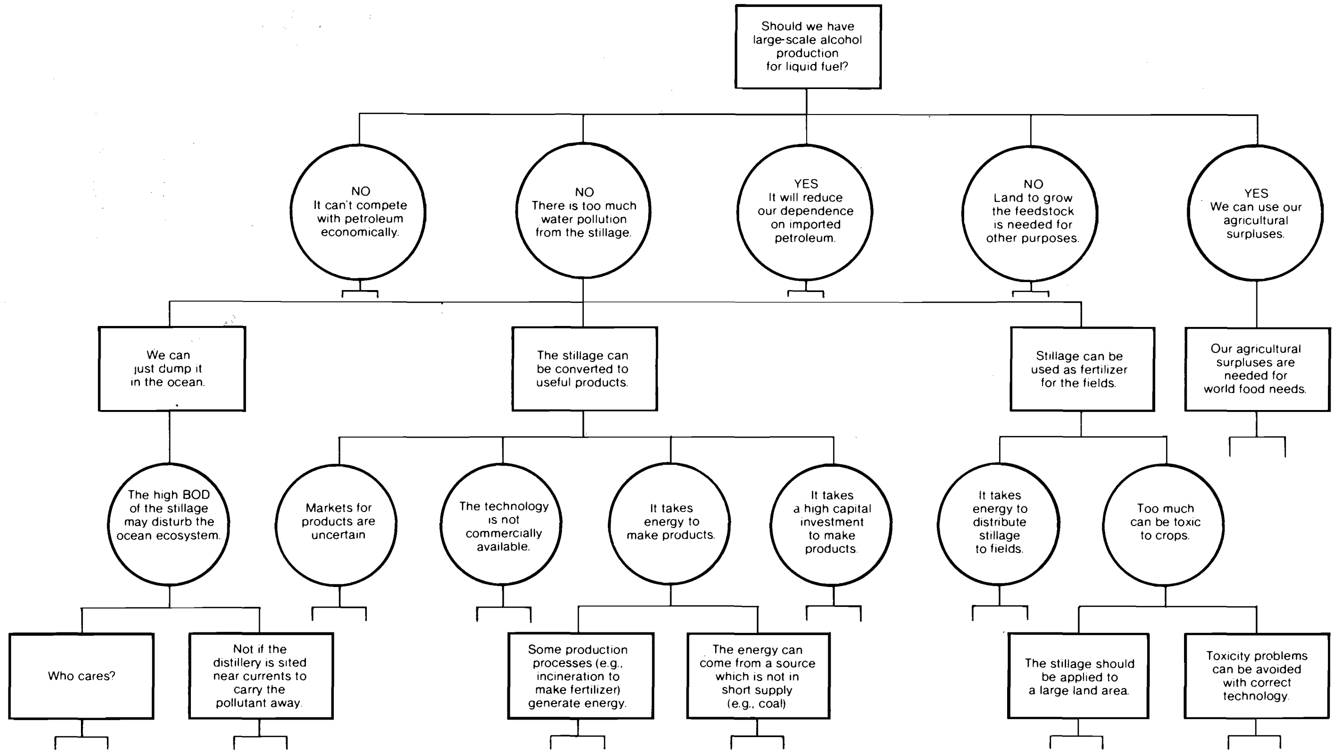

Fig. 1. Examples of issues associated with alcohol fuel development.

fore produces an additional 2000 m^3 of stillage. This volume is not excessive compared with typical volumes of industrial effluents or the hydraulic capacity of conventional waste water treatment, but when the volume of the stillage is multiplied by the concentration of biological oxygen demand (BOD), which is much greater than for sewage, the scale of the water treatment problem becomes enormous. It is possible to gain a perspective by expressing the BOD load in terms of population equivalents. Table 1 shows that a 150 m^3/day molasses distillery produces as much BOD as the sewage from a city of about 1.2 million inhabitants.

TABLE 1

Approximate population equivalents for stillage from a molasses distillery, assuming daily sewage production to be 75 g BOD per capita[a]

Ethanol production (m^3/day)	Population equivalent[b]
30	250,000
60	500,000
120	1,000,000
150	1,200,000
200	1,600,000
250	2,000,000

[a] Personal communication, Metropolitan Water, Sewerage and Drainage Board, Sydney, Australia.
[b] Distilleries using only cane juice would have population equivalents somewhat less than half of those for molasses distilleries.

Options for stillage handling

All forms of stillage contain everything that was added to the fermenter less fermentable sugars plus yeast metabolites and yeast cell contents. The exact composition of stillage depends on the raw material and distillery operating techniques. Some typical analyses of Australian stillage are in Table 2. All sugar-based stillages are low in pH and high in organic content, which gives them their high BOD. The ash content of molasses and cane-juice stillage is composed primarily of the inorganic components of the cane plant sap and is rich in potassium and magnesium. Calcium is introduced during sugar processing. The principal anions present are sulphate and chloride, and there are small amounts of phosphate and nitrogen. Molasses stillage generally has a higher organic and salt loading than other stillages.

Stillage might be handled several ways [1,3,4]:
1. Discharge to an adjacent waterway or land area.
2. Marine outfall (discharge a substantial distance from shore).
3. Return to agricultural fields.
4. Conventional sewage treatment.

TABLE 2

Typical composition of ethanol stillage

	Feedstock	
	Molasses	Cane juice
pH	4.8	3.7—5.9
Specific gravity	1.05	
Temperature (°C)	90	
BOD	45,000 mg/ℓ	20,000 mg/ℓ
COD	113,000 mg/ℓ	
Dissolved solids	10%	
Suspended solids	11%	6—11%
Ash	3%	2—3%
Organic matter	8%	5—8%

5. Lagoon treatment.
6. Anaerobic digestion (and production of methane).
7. Incineration to an ash which can be used as fertiliser.
8. Evaporation to an animal feed (or use as an aquaculture feed).

Some important characteristics of these stillage handling options are summarized in Table 3.

Brazil has employed discharge to waterways (sometimes with lagoon treatment) and return to agricultural fields [5]. Japan has incinerated stillage to a fertilizer ash, and Australia has used conventional sewage treatment, land disposal, and marine outfalls [3]. Grain alcohol stillage in the United States has been evaporated and marketed as an animal feed [6].

These options vary enormously in their environmental characteristics and the degree to which they are commercially proven, consume or produce energy, lead to useful by-products, and cost or generate money (Table 3). For example, conventional sewage treatment of stillage would result in an environmentally clean discharge, but is very expensive. It would require substantial expansion of existing treatment facilities and could add as much as 20% to the production cost of the alcohol.

Stillage handling options which require the smallest capital investment involve discharge of one sort or another. Of these, the least expensive is discharging directly from the factory, but this may have serious environmental consequences. Somewhat more expensive is discharge from an ocean outfall, which may or may not have damaging effects, depending upon local conditions. The more expensive redistribution of the stillage to agricultural fields has the advantage of utilizing plant nutrients and soil conditioners in the stillage but has the hazard of toxic effects ("overfertilization") from excessive application. Toxicity effects from field application can be minimized by distributing the stillage over a large area, but this means more expense in the distribution system.

TABLE 3

Characteristics of alcohol stillage handling options

	Stream discharge	Marine outfall	Land disposal	Sewage treatment	Lagoon treatment	Anaerobic digestion	Incineration	Industrial evaporation	Solar evaporation (open ponds)
Energy									
Net energy	0	–	–	—	0	+	+[b]	–	0
Economic									
Capital cost	L	L—M	L—M	H[a]	M	H	H	H	L—M
Operating cost	L	L	M—H	H	L	M	M	M	L
Further treatment	N	N	N	N	Y	Y	N	N	N
Useful product	N	N	Y	N	N	Y	Y	Y	Y
Environmental impact									
Land use effect	0	0	H	L	M	L	0	0	M
Water quality impact	H	M—H	L—M	L	L	0—L	0	0	0
Air quality impact	0	0	L—M	0	0	L	L	L	L—M
Odor potential	M—H	L—M	L—M	L	L—M	L—M	0	L	L—M
Flora—fauna	M—H	L—M	L—M	L	L	L	0	0	L

0 Nil
– Negative
+ Positive
L Low
M Moderate
H High
N No
Y Yes

[a]Capital cost to the distillery is low if it takes advantage of municipal sewage facilities.
[b]Varies with feedstock.

Four major products which can be derived from stillage are stock feed, fodder yeast, fertilizer, and biogas. The concept of stillage utilization implies the production and sale of marketable by-products or use by the distillery itself. The revenue from by-product sales may cover the cost of by-product recovery or even produce a profitable cash flow. However, the capital cost of recovering useful by-products is considerably greater than costs of simple disposal, often as much as the distilation itself. If markets (or internal use) cannot be found, the by-products can be of negative value to the distillery.

There are numerous trade-offs to consider in stillage handling options. A review of some of the available and potential options follows in more detail, but it must be stressed that there is no simple solution to distillery waste water problems. The choice of a stillage treatment method depends upon a number of factors:

1. The waste water characteristics.
2. Applicable ambient and emission standards.
3. Energy requirements of the distillery.
4. Economics.
5. Availability and cost of land.
6. The location of the distillery relative to receiving waters and by-product markets.

DISPOSAL OPTIONS

Marine and river discharge

The simplest method of stillage disposal is dumping it into a conveniently located body of water such as a river or ocean. Depending on the proximity of the water body, this might also be the cheapest available method in terms of capital and operating costs, including energy costs. Therefore, this method is expected to have considerable use. Although aquatic disposal of stillage can be viewed as "throwing away" a valuable resource and can lead to water pollution if carried out in excess, it can nonetheless be an attractive interim measure until a product recovery system is in place.

Environmental considerations

Table 4 lists some of the effects of stillage on water quality. When stillage is added to a body of water, the dissolved oxygen content of that water is rapidly reduced. The extent of reduction will depend on the relative volumes of stillage and water, the original oxygen content of the water, and the natural replenishment of dissolved oxygen in such forms as inflow of fresh water and surface aeration. Depletion of dissolved oxygen may proceed to a point where aerobic organism (from aerobic bacteria to fish) can no longer survive. When anaerobic conditions prevail, the waterway may become unpleasant, as foul-smelling reduced sulphur compounds are produced.

TABLE 4

Environmental impacts of alcohol stillage upon water quality and the aquatic ecosystem

*Depletion of dissolved oxygen
*Discoloration
*Odors
Eutrophication
Salinization (in fresh water)
Acidification
Increase in water temperature (locally)
*Changes in species composition of aquatic flora and fauna
Fish kills (in extreme cases)

*Most significant impacts.

Natural reoxygenation can generally replenish the depleted oxygen content of a body of water if the stillage is sufficiently diluted. The amount of dilution necessary varies with environmental conditions, but the quantities of water involved can be appreciated by considering an example in which it is assumed that the stillage should be allowed to increase the BOD by no more than 20 mg/ℓ. A 150 m^3 ethanol/day molasses distillery producing about 2000 m^3/day of stillage at 45,000 mg/ℓ BOD would require a dilution of 2250 to 1 to achieve a final concentration of 20 mg BOD/ℓ. 4.5 Mm^3/day of water would be required for dilution, a volume of water that would only be available in the ocean or a large river. Even with this dilution, the color of the final mixture would be about 30 Hazen Units, rather dark and possibly unacceptable to the public.

Effects on fisheries depend on the relative volumes of stillage and water flow. The social significance of these effects depends on the importance of fishing to the subsistence and livelihood of the communities involved. The significance for recreation likewise depends on the current and potential recreational use of the water course and its surroundings. The effects can range from destruction of fishing to aesthetic problems, such as odor or coloring of the water.

It is unlikely that the 150 m^3/day molasses distillery in the preceding discussion could discharge into anything but the largest river without an excessive effect on the ecosystem. The smaller the distillery the greater the chance that discharge to a stream could be a reasonably satisfactory disposal option. However, even a relatively small (30 m^3/day) cane juice distillery would require a stream flow of 900,000 m^3/day so as not to exceed a 20 mg/ℓ BOD increase. This flow might be available in larger river basins, but the effects on other uses of the water would have to be carefully considered.

Effects on potable water can range from minor changes in increased color and salt content to massive oxygen depletion leading to the death of fish and other organisms. Minor changes may be acceptable with current water treatment, but more drastic changes may only be correctable with increased water treatment costs. If the stream into which the stillage is discharged is used as a source of irrigation water, then stillage may actually impart some benefit to the irrigated crop. This will be site-specific, however, and depend on relative volumes of irrigation water and the nutrient requirements of the crop. In some areas, irrigation and subsequent higher water table levels are increasing stream salinity and affecting downstream users. Stillage would exacerbate this problem.

The ocean has long been considered a large, assimilative receiving body for the acceptance of discharged wastes. With sufficient dispersion, sea waters should easily accommodate the high BOD, the salt content, and the low pH of stillage.

Stillage may enter the ocean indirectly by way of discharge to an estuary or nearby stream. This would be the least-cost option for a distillery not located adjacent to the ocean. Unless the stream is large, there may not be sufficient dilution and discharged stillage may affect estuarine ecosystems. Negative effects may take the form of oxygen depletion, oversupply of nutrients upsetting nutrient balances, and color and turbidity decreasing availability of light to photosynthetic organisms. If dispersion is sufficient, the effects may be positive, with organic matter and nutrients in stillage stimulating productivity through the food chain. Because of the significance of estuaries on total marine ecosystems and their importance as breeding grounds for commercial and subsistence fisheries, an adequate assessment of potential effects is imperative.

Distilleries located close to the sea have a fairly low-cost option of piping stillage to the coast and discharging off the shore. The best chances of achieving sufficient dispersion of stillage are by deep-water discharge or carefully designed offshore diffuser systems. Barging and deep-water dumping are possibilities, but because of high capital and operating costs and dependence on weather, selection of such a system is unlikely. There could be barging of stillage that has been concentrated by evaporation, but evaporation involves an increase in factory capital and operating costs and consumes more energy.

Offshore diffuser systems are more promising. The design and location of a diffuser depends on the dilution required and on local tidal conditions, currents, and the sea floor, which can be assessed by hydrological surveys. Environmental impacts to be considered are those on the adjacent shoreline and estuarine ecosystems as well as coral reefs, which are particularly sensitive to minor changes in nutrient loadings. Ecological considerations should influence siting decisions and, in the case of coral reef systems, may dictate that a diffuser be located outside fringing reefs. Some locations are emminently suited to ocean discharge due to extremely deep water or strong coastal currents. The laying of offshore pipelines is possible but can be expensive because of sea-floor terrain. Pumping and environmental monitoring are additional costs.

Stillage as an irrigant and crop fertilizer

The use of stillage as an irrigant and crop fertilizer for sugar cane appears attractive. Sugar cane requires large amounts of water and inorganic nutrients, both of which stillage can supply. It seems sensible to return this material to the fields, substituting for purchased fertilizer inputs and supplementing irrigation.

Operational considerations

The following questions address a number of issues raised when assessing the feasibility of stillage as an irrigant or fertilizer for sugar cane:

1. What is the fertilizer requirement of the crop?
2. What is the water requirement of the crop? How much of that requirement is met by rainfall and existing irrigation? Is there a need for supplementary irrigation?

3. What is the fertilizer content and balance of the stillage? What is the volume of stillage available?

4. During what seasons are irrigation water and fertilizer required by the crop? When is stillage available?

5. How far is the crop located from the distillery? How far can stillage be transported economically?

6. How will stillage be applied? What will be the consequences of over-application of stillage?

7. Who controls the crop? How will this affect the management of stillage distribution?

8. What standards and regulations cover such an application of effluent? Who is responsible for water pollution liability subsequent to the application of stillage to a crop?

9. What is to be done with stillage or other waste water not required for the crop (because of excess volume, excess fertilizer, or seasonal reasons)?

A molasses distillery will probably operate year round, but a cane juice distillery will operate only when cane is available. A molasses distillery may be at a disadvantage for land applications of its stillage because it may produce stillage at times when the crop does not require irrigation. A cane juice distillery is usually located near its supply of cane, but a molasses distillery may be located centrally to the supply of molasses from a number of sugar mills. The salts in the stillage have, therefore, come from a large area and must be redistributed to a large area if over-application is to be avoided.

Stillage could be blended with irrigation water to deliver it to the crop, or a special distribution system such as pipelines could be installed for crops close to the distillery, but more distant sites might only be serviced by tanker, which consumes liquid fuel. The organization of stillage distribution and application is facilitated if distillery operators also control the crop to be treated. The cane for a juice distillery or integrated sugar mill/distillery complex may come from production organizations ranging from highly organized estates managed by the distillery operator to a large number of small holdings operated by small producers.

Environmental considerations

In traditional fertilizer treatment, the management question is: "How little fertilizer can be added and still achieve worthwhile increases in yield?" With stillage as the fertilizer, the objective is to minimize distribution costs. Because stillage contains considerably more potassium than nitrogen or phosphorous, the management question also becomes: "How much potassium can be added in the form of stillage before yields decline?" Effects of over-application of potassium may be short-term changes in cane quality and increases in the ash content of sugar produced from it [7].

The most important issue, however, is long-term productivity of the cane land. Experience with intensive land application of stillage in Australia (the distillery operated by CSR Limited in Sarina, Queensland) has indicated that salts can accumulate in the soil until vegetation is no longer supported [8]. Although this is reversible, the interim effects on the viability of the industry could be serious.

A significant issue is the liability for pollution and other problems caused by misuse or accidents in stillage handling. A spill of the concentrated material or heavy rainfall shortly after application to a cane field could lead to serious contamination of a waterway. If the spill, run-off, or wash-off occurs on or from a grower's property, is the distillery operator liable? Does his liability end at the distillery gate or the farm gate? Who is responsible during transport?

Another significant problem with stillage is odor, particularly in aqueous solutions, which rapidly become anaerobic. This may occur in cane fields when rain follows stillage application. Rainfall may also cause salts and color to appear in leachates from the cane fields and may affect downstream water quality. Fly breeding, which has occurred in intensively treated land disposal sites, may also be a problem in cane lands.

Stock feed (evaporation or yeast)

Stillage can be used as a feedstock for production of yeast as a high protein additive for animal feeds. It can also be concentrated to molasses consistency and added to stock feed, serving as a binding agent and providing nutrients. Stillage from corn-based fermentation has high value as a stock feed, but stillage from molasses fermentation has a significantly lower market value as a stock feed, primarily because of the large amount of potassium it contains.

Market considerations

Because molasses has long been used for stock feed, molasses stillage may find a stock feed market by replacing the molasses that has been diverted from stock feed to distilleries. Such may be the case in Hawaii, where the bulk of molasses produced is currently exported to the continental United States for use as stock feed. Many other nations do not have intensified cattle feedlot operations, so the domestic demand for stillage stock feed could be doubtful and at best seasonal. The potential for export markets may improve if more molasses is removed from the world market and large quantities of surplus grain are directed from animal feed to fermentation.

Developers of new distilleries would have to be confident of the viability of the stock feed market before committing themselves to concentration of stillage. A collapse of the market could have disastrous effects on the economics of ethanol production and leave the distillery with a stillage disposal problem. The large corn fermentation capacity under development or projected for the United States includes, in many cases, plans for the production of feeds from corn stillage. There may therefore be a large supply of feed in North America available for export. Whether sugar-based stillage could achieve an adequate price in this competitive market is debatable. Because the stillage from cane juice and cassava distilleries has significantly less nutrient value than that from a molasses distillery, it is doubtful that the capital cost involved in producing a concentrate from cane juice or cassava stillage could be justified.

The likely seasonal or export demand for stillage-based stock feed may require further concentration of the material to avoid spoilage in shipment or storage, adding to the energy costs of production.

Production methods

Evaporation of water from stillage in open solar ponds has been proposed as one method to produce a dried sludge for stock feed or fertilizer. However, large areas of land could be required, depending on factory output and net evaporation rates; and concentrated stillage is an excellent breeding medium for flies. This method could be a viable, low capital cost proposition in areas with abundant, low-cost land and an excess of evaporation over rainfall. Ponds would have to be designed and managed to minimize or control insect breeding and prevent overflow during heavy rainfall to avoid pollution of nearby waterways. Suitable methods of sludge removal, handling, and utilization would have to be developed.

The main method for producing stock feed is to remove the water by heat evaporation. Molasses stillage, however, has proven difficult to concentrate using multiple-effect evaporators, and scaling of heat transfer surfaces is a recurring problem. Stock feeds produced by an evaporation plant will be costly and require significant energy input, adding to the distillery's overall net energy requirements. Solutions to scaling problems may require complex cleaning systems, adding to capital cost and introducing another effluent requiring treatment and disposal.

Candida utilis can produce significant quantities of high quality yeast for animal feed when cultured in well aerated stillage. The stillage BOD is only reduced by about 50% in yeast production, so a substantial residue still remains. There would also be a substantial power requirement for aeration, and more complex control than is needed for the production of ethanol. Nutrients may be required to achieve yeast growth. Additional fermenter capacity (about equal to that used for ethanol production) would be required, as well as yeast recovery equipment (such as centrifuges) and dewatering equipment (such as drum rollers). Capital costs and operating costs are high, and the risks to be satisfied by a market return for the yeast are, therefore, substantial. Establishment of secure markets for yeast is essential before making a commitment to this option.

Fertilizer (incineration)

Market considerations

To the extent that potassium and other salts in stillage can replace purchased fertilizer inputs for farming, stillage or isolates from it will have a market value. The value at the farm gate will depend on the value of the replaced fertilizer, the compatibility of the stillage material with existing application practice, and the possible need for purchases of other materials to supplement nutrient imbalances in the stillage fertilizer. The market value will have to be sufficient to cover the recovery and distribution costs of the stillage fertilizer, including capital costs. In 1978 stillage from the Sarina, Queensland distillery in Australia (50,000 m^3/yr capacity) had a value of about US$6.5 million when expressed in terms of the commercial fertilizer it might replace [8]. The stillage stream contained approximately 1100 Mg nitrogen, 100 Mg phosphorous, 6300 Mg potassium, 1200 Mg calcium, and 800 Mg magnesium. Such a high potential value is sufficient to generate an interest in recovery and distribution, but the potential can only be realized if the material can be delivered to the farm in a usable form at a price competitive with conventional alternatives.

Production methods

Concentration of stillage nutrients could be effected if the organic components were retained by a membrane allowing passage of salts only. Because a significant proportion of low-molecular-weight organic matter is present, a membrane with a cutoff at molecular weight 1000 would be required. Some laboratory work has been done, and there is a great deal of potential for improving the technology in this area. Electrodialysis techniques have also been proposed but much work remains before such systems can be applied on a commercial scale.

Incinerators can be designed to produce a soluble ash product with excellent potential for use as fertilizer. This has the advantage of facilitating transport and distribution because of the low volume of the material. Because the ash has a relatively high quantity of potassium, however, and farmers are accustomed to using a balanced fertilizer, it may be necessary to upgrade the ash by adding nitrogen and phosphorus.

In addition to the ash, stillage incineration produces heat that can be used for process steam and electricity generation, improving the net energy balance of a distillery. Stillage incineration is not yet well established but is under development. Incineration facilities, with their attendant evaporation plants, heat recovery, and ash handling systems, involve high capital costs. (Estimates are about US$25 million for a 50,000 m^3/yr molasses distillery.) Advantages of incinerators are complete removal of BOD and excellent heat recovery. To prevent air pollution, fly ash recovery must be an integral part of the incinerator plant.

It is logical for operators of molasses distilleries to look to adapting the incinerator technology of other industries. The incineration of aqueous liquid organic wastes has been established for some years, especially in the pulp and paper industry.

Japanese industry built a number of stillage incinerators in the early

1970s. These first generation incinerators were characterized by high capital and operating costs. The plants were large, sometimes as big as the distillery itself and, therefore, difficult to install in cramped industrial estates. Stillage was evaporated to about 40% solids in multiple-effect evaporators and then introduced to the incinerator's combustion chamber with atomizing steam. A supplemental fuel (oil or natural gas) was often required to sustain combustion, and steam generated in the boiler was usually sufficient only for the stillage evaporation plant. Problems associated with the operation of evaporator-incineration plants include scaling of evaporators and maintaining combustion temperatures to prevent overheating, which can cause fusion of the ash to an insoluble glass with no fertilizer value.

The potential for energy recovery from stillage depends on the feedstock. The low solids content of cane juice stillage and its lower potassium concentration means that it will require more energy for evaporation, and the product ash will be of lower value than that from molasses, although most cane juice distilleries will have bagasse available for fuel. It may be difficult to justify the high capital expenditure of incineration for a cane juice distillery.

Stillage from Australian molasses is characterized by high solids content and high calorific value. A feasibility study of incineration for one Australian distillery has indicated that steam can be produced for all the electrical and process steam requirements of the distillery. This would replace dependence on imported oil. The company that operates the distillery is investigating detailed designs for a commercial plant.

In summary, the incineration of stillage is attractive for operators of molasses distilleries. It makes possible virtual independence from external energy sources, demand for water is significantly reduced because of condensate recycling, and potassium can be returned to cane farms. The problems are:

1. there is no new-generation incinerator yet in commercial operation for stillage;
2. capital costs are high, probably of the same order as the cost of the distillery itself;
3. incineration is probably not a viable option for a cane juice distillery.

Methane (anaerobic digestion)

Market considerations

Because of the high organic content of stillage, anaerobic digestion offers a prospect of financial return from methane production. Given adequate time in the digester, up to 95% of the BOD can be removed, producing a gas that could supply all of a molasses distillery's fuel requirements (and perhaps 30% of the requirements of distilleries operating on cassava or cane juice). In the case of a molasses distillery, the potential fuel saving is significant. If that saving is sufficient to cover the capital cost of the digester and the further treatment and disposal of its effluent, methane production should be seriously considered.

In the case of a cane juice distillery, the methane may have little value if the distillery's fuel requirements are already met by bagasse. If the bagasse is used in the manufacture of paper or as a source of cellulose for hydrolysis and subsequent fermentation, there will be a fuel requirement that could be met by methane. Methane in excess of a distillery's fuel requirements may find a market in other industrial or domestic uses. This could require decisions on such issues as sharing of reticulation costs and pricing policies, but it may be feasible in regional industrial developments.

Use of anaerobic digestion for stillage treatment has until recently been considered uneconomic because of the long residence times (and hence large digester capacity) required to achieve a reasonable degree of BOD conversion to methane. However, the high costs of energy have prompted new research into the application of anaerobic digestion to distillery wastes.

Production methods

Current research is aimed at increasing the rate of microbial breakdown of BOD. One potential method is to use thermophilic bacteria (functioning between 50° and 60°C) rather than the normal mesophilic groups (30° to 40°C). This method is suited to a distillery operation because of the high temperature of stillage. Other research is aimed at optimizing sludge return rates and gas recycling and quantifying the requirements for nutrient supplements. The sludge produced in the digestion process has considerable potential as a fertilizer, but sludge handling, dewatering, and distribution systems will have to be identified to capitalize on this potential.

Even at 95% BOD reduction, the residual BOD of the digester effluent is still high, and much of the coloring material and dissolved inorganic salts will still be present. The digester effluent could be discharged into an ocean or river or returned to crop fields as is, but the environmental complications of direct discharge and land application then apply. Local conditions and environmental regulations may dictate further treatment of the digester effluent to reduce BOD and color. This might entail aerobic treatment, settling, or flocculation and color removal by carbon treatment or ozonation. These additional treatment requirements may consume a large amount of the energy generated by the methane, so the overall net energy balance of the system could be significantly less than first expected. The salt loading remains, and this will influence the final disposal method of the treated effluent.

Stillage from molasses usually has a high sulphate concentration, and under anaerobic conditions sulphate is reduced to sulphide, either hydrogen sulphide gas or dissolved sulphides. Hydrogen sulphide in product gas can cause air pollution problems when it is burned. Research is under way to reduce sulphides by gas stripping and recycling [9].

Even if anaerobic processes can reduce 95% of stillage BOD in short periods (e.g. 5 days), considerable problems remain. At 5 days residence time, the anaerobic digester will require a capacity at least three to four times the distillery's fermenters. Large digesters could have high capital costs if tanks are used. Lower-cost, in-ground digesters could be built but would require novel gas recovery and sludge removal systems. Investigation for a molasses distillery in Australia has shown that for anaerobic digestion, aerobic secondary treatment, and color removal by ozonolysis, the required capital cost is at least as great as that for an evaporator/incinerator complex for the same size distillery. There still remain operating costs and management problems of hydraulic loading of the treated effluent.

Application of anaerobic systems to cane juice distilleries is complicated by the seasonal nature of the availability of cane. Anaerobic digesters, like most other biological systems, are difficult to start up and would be slow to attain stable operating conditions at the start of each cane season. There would be fewer problems for a multiple feedstock distillery that can operate on cassava or molasses when cane is not available.

IMPLICATIONS FOR ENERGY DEVELOPMENT POLICY

Costs

Stillage disposal is a cost of production dependent on environmental standards and returns from any stillage by-products or recoverables. Some stillage options can replace or supplement purchased fuel and reduce energy inputs which are a significant component of production costs. Energy-producing options like incineration and anaerobic digestion, however, involve such high capital costs that the capital component of production costs rises accordingly.

The fact that very little of the energy-producing technology has achieved commercial status with stillage treatment may make the risks of so large a capital investment unacceptable. The absolute supply of capital may also preclude expenditures on high technology options, when it is considered that the capital cost of a molasses stillage incinerator may be the same as the cost of the molasses distillery itself.

Other stillage utilization technologies which produce potentially saleable by-products may also involve appreciable capital investment. A distillery developer will want to be assured of the commercial status of the technology and the existence and viability of the market for the by-product before capital is outlayed for its recovery. The viability of markets can be expected to be country- or region-specific.

A distillery developer can be expected to select a stillage disposal option that involves the least net cost of operation and the lowest capital cost, consistent with prevailing environmental standards. He cannot be expected to build one molasses distillery complete with stillage incinerator instead of two similarly sized distilleries with less sophisticated stillage treatment and the same capital outlay, unless pressures from environmental policies outweigh simple cost effectiveness for energy production.

Environmental standards and distillery siting

The unique disposal considerations for stillage suggest that environmental agencies should reassess conventional water quality standards before applying them to stillage discharges. Standards based on best practicable or best available means will have to recognize the high cost and high risk of these stillage treatment options. The fact that they are available on a pilot scale does not mean they will be easily applied at a commercial scale. Arguments that the value of the stillage by-products will justify the expense for their recovery fail to recognize the non-commercial status and potentially high costs of these recovery methods and the uncertain market value of many of the by-products.

National emission standards alone are not appropriate for regulating stillage discharges, because emission standards for aquatic discharges should be tailored to each body of water. Ambient standards are more meaningful but still have operational problems unless a distance from the point of discharge is specified and an appropriate and achievable standard assigned. This means appropriate and achievable in terms of the assimilative properties of the body of water and the ecological and socioeconomic consequences of exceeding a certain level of water quality degradation.

In discussions about high-technology stillage utilization systems, it must be recognized that a low technology disposal option might be not only most appropriate economically for a distillery but also satisfactory environmentally, depending on the site. The siting of a new distillery depends on several considerations. For a distillery using an existing molasses resource, the location might be a compromise between feedstock availability, access to the market for ethanol, and socioeconomic considerations such as availability of labor or competition for use of water. For a new cane juice distillery, the key factors are the availability of land for cane agriculture, the social infrastructure, and the availability of water for the crop and the factory. It is important for effluent disposal to receive equal attention with these other considerations in distillery site selection. Governments need to devise policy measures to ensure that this happens so that the potential for environmental conflicts is minimized at an early stage.

Government policy

The stillage problem of each distillery needs to be assessed individually in view of its specific site, scale of operation, and feedstock. As environmental regulatory agencies work with distillery operators to develop appropriate standards for each distillery's operation, the agencies need guidance from government policy on how to weight trade-offs between energy production and environmental quality. Some governments may see their current energy and trade deficit problems as superceding the need for maintenance of environmental standards, at least in the short term. In making such decisions, governments need to assure themselves that they are as fully informed of the consequences as possible.

There are strong arguments for the need to "get it right" the first time. Once established, a distillery will not only be part of the national fuel economy, but it will also be entrenched as a key element in the regional economy, with the incomes of many people depending on the distillery and the government having invested in the infrastructure to aid its development. The costs of retrofitting may be beyond the resources of a distillery's operation, and arguments about its regional significance may sway the government to accept unsatisfactory environmental performance. Alternatively, the government may find it has to increase ethanol market prices to stimulate an improved environmental performance, or it may have to spend more to remedy the problems caused by the distillery.

If a government depends on private industry as the source of investment capital for distillery developments, then clearly defined government policies are required on matters such as tax policies and the market price of ethanol. Government requirements concerning environmental performance will keep investors away unless their income will be sufficient to cover the capital and operating costs of facilities required to achieve that performance. Investors need to see consistency in the government's position on both environmental standards and pricing policies before capital is committed.

Distillery developers might contend that the costs and market uncertainties of more complex stillage treatment technology do not justify the initial capital outlay. It could be argued that a premature commitment of large amounts of capital to inadequately developed technology is a poor choice, and environmental quality might suffer if the operation fails commercially. Developers may, therefore, suggest that they be allowed to choose a low-cost disposal option such as aquatic discharge, and after generating a cash flow and accumulating some profits, later install more costly product recovery.

There appears to be room for compromise in the early stages of distillery development. The duration and extent of compromise needs to be clearly defined by a stated government policy on environmental quality. Compromise implies an on-going assessment of developments in stillage handling technology by both distillery operators and environmental regulatory agencies, accompanied by an evaluation of the performance of the initially installed technology and a constructive dialogue between the parties.

The achievement of a balance between energy production and the maintenance of acceptable environmental quality is a major goal of all nations. Standards should not be so unrealistically stringent as to discourage development, but they should not be so lenient that major environmental disruption and increased social costs ensue. Many less-developed countries suffer from a shortage of capital that limits their available options, and in the urgency of their energy situations they lack the professional manpower to do a thorough job on the assessments, standards, and policies appropriate to their needs and aspirations.

A proposed clearing-house for stillage processing information

Serious consideration should be given to the way in which stillage will be managed, from the earliest stages of planning a new distillery, including decisions on where the distillery will be located. A distillery planner might ask the following questions:

1. What are the markets for by-products such as methane, fertilizer, or animal feed?
2. What is the risk of a process which is not commercially proven?
3. How much capital is available?
4. Is it necessary that the process pay for itself?
5. Must the process be self-sufficient in energy?
6. Will the distillery serve a large area or a small area?
7. Can the distillery be located near the ocean?

Although the answers to these questions should suggest which stillage option is most appropriate, there will not necessarily be a simple solution. It may be necessary to return to the questions and decide where compromises will be made among the kinds of considerations shown in Table 3. Compromises are matters of policy, and a realistic policy can be shaped only to the extent that the practical possibilities for stillage handling are dealt with explicitly and realistically in the fuel alcohol development process.

It is essential that both distillery developers and environmental agencies be fully aware of the potential environmental significance of stillage. They should be well informed on past and present commercial experiences with stillage handling so they can relate environmental quality aspirations to the practicability of achievement. There are numerous commercial systems for processing alcohol stillage which are now under development in different parts of the world. Many have been adapted from processes already in use for other industrial effluents with similar properties. Some are already in use, others are only in the pilot stage, and still others are in laboratory development. The manufacturers and developers of these systems make varying claims about them, some valid, others not.

It is difficult for anyone deciding on stillage management to know what systems are available and which is appropriate for the circumstances. It is likely that decisions will often be made on the basis of partial information because a comprehensive survey of stillage systems would be excessively costly for a single distillery. This would be particularly true in a crash program where there is little time to assemble information and insufficient professional manpower.

There is, therefore, a need for a clearing-house of information on stillage management technology. This information should include specific equipment and processing systems available or under development. Each system should be documented with respect to the capital costs of the equipment, the kinds of stillage (with respect to distillery feedstock) that the process handles, the energy budget of the process and the characteristics of its products. It should allow someone who is setting up a new distillery to evaluate different stillage handling systems with respect to the particular circumstances of the distillery, matching candidate systems to the sources of energy available, calculating costs in terms of energy inputs and other requirements of the system, evaluating by-products with respect to local markets, and evaluating emissions with respect to local standards. At a national level this information could be used to evaluate the feasibility of establishing alcohol distilleries on a large scale.

Although there is not now any established clearing-house for this sort of information, a study conducted by the Hawaiian Sugar Planters Association [4] represents a significant first step in this direction. As there are numerous systems that have not yet been catalogued and described in a manner most useful for planning and developing large-scale alcohol production, there is an opportunity to do so in a way that could have a significant impact on liquid fuel development.

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