Lagooning and Treatment of Waste Water

W. W. BARR[1]

Received for publication February 15, 1962

The disposal of waste waters from factories of the sugar beet industry has been given increasing attention by various federal, state and municipal agencies. With the growth of municipalities and the industries in and about them, the need for water supplies of domestic quality becomes more acute for all competing interests. The results of the enactment of legislation over the years to combat stream pollution are evident in most areas served by our industry. The beet sugar industry can rest assured that within a few years, adequate facilities for the treatment of our waste waters will be in effect in all areas.

The American Crystal Sugar Company, in the operation of nine plants in six states, has become fully aware of the problems entailed in waste water disposal and stream pollution. Laboratory facilities for the sanitary analysis of waste water are presently provided at six of our plants. The states of Iowa and Minnesota have recognized for quite some time that the direct return of waste water to a receiving stream (even though it may be screened and subjected to a sedimentation treatment) will not, by dilution, effect a desirable oxygen balance in that stream. Although Minnesota possesses adequate ground-water reserves, river flow in the areas of American Crystal Sugar Company's plants is quite variable and on the average is not of large volume.

A practical solution to the problem of handling high volume beet sugar wastes, high in suspended and soluble organic matter, has been the use of stabilization ponds. The construction of trickling filters, activated sludge systems, clarifiers and the like, even for treatment of relatively small volumes of highly contaminated water, does not appear to be entirely suitable from either a cost or an operational standpoint, particularly under adverse weather conditions. With campaigns extending to 130 days, one can expect a number of days when the maximum temperature is zero or below, necessitating the processing of storage beets with a certain percentage frozen. A continuing increase in the strength of the waste water, measured as biochemical oxygen demand (BOD), is noted as the campaign progresses.

The first steps by the American Crystal Sugar Company in the lagooning of waste water over winter, were taken at the Mason City, Iowa, plant in the early 1920's. A study was instituted there in 1946 to obtain information on sedimentation and the oxidation

[1] General Chemist, American Crystal Sugar Company, Denver, Colorado.

rate of impounded wastes during the early part of the season when biological activity would be in effect. Segregating the water from early campaign in one pond, the study was continued into the spring months during the period of discharge. On the basis of this work, authorities of Minnesota and with the sanction of North Dakota, granted a permit for construction and approved the operation of a lagoon system at the new Moorhead plant for the 1948 campaign. Similarly, a like plan was put into effect in 1954 for the Crookston plant.

Since the major rivers in the area provide the means of final disposal of waste waters, some facts on these waterways are in order. The Red River of the North, formed by the confluence of two smaller streams in southeastern North Dakota, forms most of the boundary between North Dakota and Minnesota in its 394-mile flow to the international boundary and thence into Lake Winnipeg. The river distance is about twice that of the road distance. The one-half foot drop per river mile causes a relatively sluggish condition which effects considerable buildup of sludge deposits during periods of normal flow. Anaerobic decomposition of such sludge causes some material to go into solution while partially oxidized matter goes into suspension. This is of some concern in determining the allowable or calculated volume of waste water that can be safely released since the effect is an increased BOD of the river and decreased dissolved oxygen content. Such a condition, particularly during periods of ice coverage, produces a serious negative oxygen balance.

The Moorhead plant draws water from the Red River just above the Moorhead sewage treatment plant and discharges its waste about a mile below. The Fargo sewage treatment plant discharge is approximately six miles below our outfall. Overloading of both municipal plants curtails our discharge numerous times during the course of a year.

The East Grand Forks plant, situated at the junction of the Red River and Red Lake River, draws its water from the latter as does the Crookston plant 48 river miles upstream. Our plant and the City of Crookston, both employ lagoons and discharge their effluents into the Red Lake River. The twin cities of Grand Forks and East Grand Forks and our plant at East Grand Forks all discharge into the Red River. A new lagoon system constructed at the East Grand Forks plant in 1961 replaced the sedimentation pond constructed in 1934 which allowed only about one day's retention. The city has had a lagoon system in operation for about a year. River flow there has averaged about 2,300 cfs as compared to about 500 cfs at Fargo-Moorhead. There are extended periods during the operating season when the river flow at Moorhead-Crookston ranges from 50 to 100 cfs.

Since none of our Minnesota plants employ the Steffen process, we are not confronted with that waste problem. The three plants are each provided with separate pond areas for lime flume wastes. Facilities are such that after stabilization the effluent may be discharged into the lagoon system.

Some change is to be noted during the last few years in the provisions of the Minnesota Water Pollution Control Commission's approval for construction and permit for the operation of sewerage facilities. The provisions for both the Moorhead and Crookston plants are basically as follows:

1. That no liquid wastes will be discharged from the lagoons during periods of ice coverage in the stream.
2. That wastes will be held in the lagoons and the rates and conditions under which the wastes are discharged will be controlled so that:
   (a) Dissolved oxygen (DO) of the water in the river below the outlet of the plant wastes will not be reduced below 3.0 parts per million;
   (b) A positive oxygen balance (dissolved oxygen greater than the 5-day 20° C biochemical oxygen demand) will be maintained at all times;
   (c) The wastes will not have a deleterious effect on domestic water supplies taken from the river below the plant.

The conditions for the new system at East Grand Forks stipulate that:

1. The total available discharge capacity will be sufficient to allow discharge of the contents of the pond within a period of one month.
2. That the release of the wastes be controlled as may be necessary to avoid depleting the dissolved oxygen of the receiving waters below 3 mgm/liter at any time as shown by adequate sampling records, and that there be no deleterious effect on domestic water supplies, or any material interference with other established uses of the river below the point of discharge.

These latter provisions imply that no discharge should be made to the river during periods of ice coverage. The second item in the East Grand Forks permit is based in part on studies made during the spring months of 1960 and 1961. Investigations were made to determine the effect of releasing large volumes of waste water to the river with high initial DO, during the period of high run-off and low water temperature, in terms of dissolved oxygen, BOD, and total dissolved solids. Control was aimed at maintaining a river DO of about 5ppm residual, determination of threshold odor concentrations or odor quality and establishing the location of the sag point in respect to DO. The Moorhead factory established a series of 15 sampling stations extending 90 river miles downstream, where the plant at East Grand Forks took over the survey and continued for about 90 river miles beyond the city. With initial pond BOD's in the order of 1,000 and 1,700 at Moorhead and Crookston, respectively, maximum discharge ranged from 15 to 40 M.G.D. in March 1960. The fact that both the Red River and Red Lake River flows were adequate to absorb a high volume rate of discharge of the factory wastes, as indicated by a favorable DO content, was viewed with enthusiasm by our company as well as state authorities. On the basis of previous control measures only a fraction of that volume could be released. Prior to this the rate was governed to concur with the stipulations of the permits and estimated from graphic charts furnished by the Minnesota Department of Health. These charts, showing allowable discharge at various BOD levels of waste, correlated to stream flow, are based on this fomula:

$$\frac{\text{(M.G.D. stream flow -15) 6}}{\text{ppm BOD of Waste}} = \begin{matrix}\text{M.G.D. allowable waste discharge}\\ \text{at river temp. } 4^\circ \text{ C, open water}\end{matrix}$$

In the above case applicable for Moorhead, 15 is the minimum stream flow at or below which the river should receive no waste. This value for Crookston is 35. Six ppm dissolved oxygen are indicated to be available for BOD stabilization in water, at 4° C, saturated in respect to oxygen. With a receding river and increase in river water temperature, control measures revert from the basis of maintaining a residual 3 - 5 ppm DO to that of positive oxygen balance. It is hoped that with adequate treatment and stabilization, along with sufficient river flow, that the bulk of the wastes can be returned during early spring. With the inception of this development, it has also been to the company's advantage to follow this latest method in mid-campaign prior to river freeze-up.

Each of the factories pump 5 to 6 M.G.D. on the average from the rivers. In the case of Moorhead and Crookston approximately 0.2 - 0.3 M.G.D. go to the pulp drier ash flume system, where the screened water overflows directly back to the river. With the use of fresh water or seal tank water the BOD is normally in the range of 15 to 25 ppm. The re-use of pulp press water in diffuser supply has materially reduced the load to the ponds. Pulp press water, with BOD values of 2,000 - 4,000 ppm, and a volume of 130 - 160 gallons per ton of beets, can be quite offensive in a lagoon.

Recirculation of faenger water at East Grand Forks has also aided in reducing the over-all load. In addition, recirculation of flume water from 15 to 55%, has decreased the water requirements. However, this practice does tend to increase the BOD of the final water entering the ponds. A traveling screen arrangement at Moorhead and Crookston and a traveling drag at East Grand Forks remove a great portion of the bulky solids. Admittedly, a vibrating screen system would be more effective. Increased re-usage of partially stabilized pond water in beet fluming and segregation of condenser water and re-use after cooling are quite probable as the problem of waste disposal becomes more acute.

The Moorhead factory lagoon system consists of two areas 45-acres by 13-feet deep, one 50-acres by 10-feet, one 43-acres by 6 feet, and a limepond of 34-acres by 6-feet. The arrangement is such that all water leaves through one pond into a 24-inch Parshall flume and hence into a 30" pipeline to the river. Crookston is provided with three 48-acre waste water ponds by 13-feet deep and an 11-acre lime pond. The water discharges through an open ditch to the river.

The new East Grand Forks lagoon of 840 M.G. total volume, has a surface area of 155 acres and effective depth of 17 feet. It is divided by dikes and breakers into eleven bays in series. The breakers are arranged to allow for maximum water travel from inlet to outlet. The lagoon is laid out with a three-foot barrow pit which allows for the retention of about 110 M.G. to provide seeding action for the next campaign. The outlet on through a Parshall flume is designed for a maximum discharge of about 17 M.G.D. Average DO and BOD results for the greater part of the 1961 campaign at East Grand Forks are presented in Table 1.

The lagoon system of waste water disposal is not problem free. Cities are closing in on the once rural areas and the public is generally not in favor of these installations, largely because of the odor problem. It has been found that except for the lime ponds, this nuisance is usually noticeable the first week of the spring discharge (as the result of anaerobic decomposition). The reduction of various sulfur-containing compounds to hydrogen sulfide does create an offensive odor. The gas appears to build up a substantial pressure under ice cover as evidenced by the turbulence at the outlet. Light to moderate winds frequently carry the odors over the urban areas while strong winds, particularly after the ice is out, raise havoc with the dikes. Other objectionable features are dike maintenance, solids removal and seepage to adjoining properties. Probably the main concern is the buildup and retention of the flora and fauna responsible for the necessary biological and bacteriological activity.

An intensive study on the lagoon method of disposal of beet sugar wastes was performed at Moorhead in 1949 - 1951 by the Minnesota Department of Health in collaboration with the U. S. Public Health Service. The purpose was to determine the amount of pollutional constituents in the waste and the degree of reduction of these constituents which occurred by lagooning the waste water during campaign and after winter storage.

The following conclusions were reached:

1. The initial rapid settling of suspended matter appeared to account for all the reduction found in total amount of 5-day BOD, COD, and total solids over the entire period of lagoon storage. The studies indicated that 53% of the 5-day BOD, 87% of the total solids, and 97% of the suspended solids were removed by lagooning.
2. A high ratio between total solids and suspended solids indicates that a large part of the waste present in the lagoons are in true solution even at low temperatures.
3. The total amount of constituents as BOD or solids remain essentially the same over winter lagooning. A BOD of 32 for the ice phase was used in the calculations.
4. An average of 20,300 pounds of 5-day BOD per day were discharged to the lagoons. This was equivalent to 7.1 pounds of 5-day BOD per ton of beets sliced and an average 5-day BOD concentration of 455 ppm.

   Total solids of the waste water to the lagoons averaged 6,470 ppm, equivalent to 96 pounds per ton of beets sliced, while suspended solids averaged 4,920 ppm, equivalent to 75 pounds per ton of beet sliced.
5. There was little or no biological activity effective in reducing the strength of the waste at the near or below-freezing temperature.
6. The rate constant k appears to be of the same order as that for domestic sewage.

It has generally been established that larger forms of aquatic flora and fauna originally present in the lagoons tend to disappear as the season progresses. Likewise it has been noted that the coliform group of bacteria decrease, for example, from a maximum MPN per 100 ml of 350×10^6 in mid-September to $.13 \times 10^6$ in mid-March of the following year. Similarly, the well-established volumes of plankton show a trend toward extinction as campaign progresses. We usually find that as the depth of the water is lowered, allowing for sunlight penetration, that by the middle of May a red algal growth becomes quite pronounced.

This condition continues for about a period of a month when the green algae take over. As this growth increases a definite rise in pH is noted, and provided the BOD has already decreased to about 100 ppm, a super-saturation in respect to dissolved oxygen to the extent of 20 ppm is likely to occur. This, of course, brings about a rapid BOD reduction. For example, a pond of about 250 ppm BOD on June 1 dropped to 60 ppm BOD on June 10. This may be attributed at least in part to the condition of aerobic decomposition in the shallower water, with the ensuing production of carbon dioxide, carbonates, nitrites, and nitrates, which have been reported to stimulate the growth of algae.

To obtain as much bio-activity as possible during the warmer months of campaign and a continuation in the spring months, an application of a commercial enzyme material was first tried during the 1958 campaign. At that time 300 pounds were added to the south pond. However, since the enzyme systems were reported to be inactive at temperatures below 40° F, little benefit was expected that fall. The following spring in a series of analyses on the treated and untreated ponds and extending from April 15 through June 5, the untreated pond BOD average was 370 ppm as compared to 225 ppm in the treated south pond. With this note of encouragement, the treatment was extended in 1959 campaign, when 700 pounds of the material were applied to all ponds, including 300 pounds to the lime pond. The application to the final pond, through which a small discharge was maintained, was withheld until November 1. Again during the 1960 campaign a further quantity of the enzyme material was added concentrating more on the lime pond and the two ponds farther out. Of the 700 pounds used this past campaign, over half was applied to the lime pond.

The significant reductions in BOD at Moorhead prompted us to expand the program this past season to include Crookston and East Grand Forks. A total of 700 pounds of the material was added at the East Grand Forks lagoons at a rate of 50 pounds per day. Unfortunately, the comparative survey may not be as gratifying as we had anticipated, since each factory discharged from 120 - 190 M.G. of waste water during this campaign. We trust that the material was distributed so that a good portion remains.

For the program at Crookston, where high lagoon BOD values have been most prevalent, one ton of Milorganite, a product of the Sewage Commission of Milwaukee, Wisconsin, was used. It is difficult to get specific technical data on the commercial enzyme product, other than advice on the use and application. The supplier advised that the enzyme-containing material was compounded specifically for the type of waste material and pond conditions existing at our plants. It has been formulated to give the best action in darkness and under anaerobic conditions, with the water depth at least 3.5 feet. An individual in the fermentation industry suggested that it is basically a dried activated sewage sludge, with very little enzyme activity and a relatively low count of viable organisms. This has been somewhat confirmed by our bacteriologist who reported finding 7,400 bacteria, 0 yeasts and 10 molds, per gram. Somewhat disappointing were the lower results on a sample of Milorganite, with 220 bacteria, 0 yeasts, and 20 molds per gram. It may not be possible to obtain as satisfactory results with Milorganite. However, the fact remains that although we know little of the actual mechanism or the constituents responsible for the decomposition and stabilization of the waste products, the enzyme material has aided in providing a good biological environment.

Although these lagoons are usually considered to function under anaerobic conditions, the reaction in them cannot be so considered at all times because of the relatively large surface area. The over-all process of decomposition involves a number of factors. The various microorganisms consume the colloidal and dissolved solids for cell division and metabolism and, in the process, secrete enzymes which are capable of peptizing or liquifying collodial particles. It is reported that certain oxidative enzymes of microorganisms may be effective whether the organisms are alive or dead, provided that the enzymes have not been destroyed by the killing action. Such systems could be a contributing factor in our lagoon stabilization. Protozoa and various macroorganisms are capable of ingesting particles of organic matter. Upon occasion, during the summer months when the lagoon is quite active, large populations of organisms, such as the crustacea have been seen. It has been suggested by wild life authorities that the many migrating birds who rest at the lagoon, contribute to the pond seeding.

We can detect to some degree the relative activity within a lagoon by the conventional BOD analysis. By this we do not mean to imply just the comparison of results as the days or weeks progress, but another factor. This is the comparison of incubated dilution samples seeded and unseeded, using an acclimated seed source. For a true indication of the BOD of the lagoons, we find it necessary to seed the samples in the early months when a more sterile condition prevails.

It is normal to expect a gradual build-up of the BOD concentration in the waste water both to and from the lagoons, as campaign progresses. Input values range from 150 to 250 ppm, increasing to 1,200 to 1,500 ppm. After a certain stage is reached, the biological activity declines and the effective BOD removal is mainly that of a decrease in the total and suspended solids. It is felt that the new East Grand Forks system functioned exceptionally well in the first year of operation. A tabulation of the data presented (Table 1) summarizes the analysis for most of the campaign. Based on the average of 445 ppm BOD of water entering the lagoons from September 30 to November 29 and a BOD of 195 ppm at the outlet during the October 19 to November 29 period of discharge, a 56% reduction was effected.

Some positive indications as to the merit of enzyme treatment is provided by some examples. A series of eleven comparative tests was made at Moorhead from October 16 to December 16, 1959, during which time the BOD loading to three ponds was approximately the same. The south pond had been treated with 300 pounds in 1958 and 100 pounds in 1959, the east pond with 200 pounds in 1959, and the north pond with 100 pounds late in the season of 1959. The south pond, with well-established bioactivity, averaged 252 ppm BOD compared to 563 ppm in the north and 380 ppm in the east. With a large volume discharge from the lagoons in the spring of 1960, the water level was down to the barrow pit or permanent retention volume before any further significant reduction in BOD could occur. However, with the well-seeded water remaining and the additional enzyme treatment that fall, the south pond BOD values were reduced to, and remained at, the lowest levels in our experience. These BOD values ranged from 18 to 135 ppm up to the middle of December, while only a 150 ppm BOD was noted on March 22, 1961, compared to 875 ppm in the north pond. As this north pond provides the direct connection from all other ponds to the outlet, it could be expected to be well provided with seed from the other ponds, but the effectiveness is lost on the discharge to the river before any appreciable action can occur.

The continued application of the enzyme material to the lime pond area at Moorhead has also proven to eliminate a high BOD and odor problem. It is not uncommon for settled lime flume water with a highly variable initial BOD to increase to some extent as the pond starts working. Lime water BOD values have been as high as 8,000 ppm, decreasing by natural action over summer to 50 ppm or less. It was noted at Moorhead in the spring of 1960 that this pond BOD dropped from 5,900 ppm to 2,000 ppm in the three-week period of May 26 to June 16. On May 25, 1961, the BOD was 750 ppm and the pond area com-

Table 1.—DO and BOD averages, East Grant Forks — 1961 campaign.

Dates	Red River												Waste water					
	Junction with Red Lake Riv.		Above dam		300 Yards below dam		3 Miles below dam		16 Miles below dam		28 Miles below dam		To ponds	Bays 1-2	Bays 5-6	Bays 9-10	Outlet at ponds	Outfall at river
	DO[1]	BOD[2]	DO[1]	BOD[2]	DO[1]	BOD[2]	DO[1]	BOD[2]	DO[1]	BOD[2]	DO[1]	BOD[2]	BOD[2]	BOD[2]	BOD[2]	BOD[2]	BOD[2]	BOD[2]
9/30 - 10/18	9.4	4.8	8.6	5.9	9.7	5.1	8.7	7.6					400					
10/19 - 11/29	13.6	5.7	11.2	7.6	11.9	11.9	11.0	20.0					464				195	210
11/30 - 1/12	9.1	3.8	8.8	8.8	11.3	7.2	9.4	16.3					619					10
9/30 - 1/12	11.4	5.0	10.0	7.5	11.3	9.4	10.1	17.0	8.4	9.2	8.1	7.9	499	335	468	349		166
Minimum	0.5	1.4	1.8	2.8	7.8	3.8	5.0	5.8	1.1	3.8	0.9	3.2	230	384	300	100	20	
Maximum	21.7	9.8	17.3	13.8	11.6	22.4	11.6	31.8	12.6	18.0	12.4	24.1	1320	1020	848	777	543	

[1] DO = ppm Dissolved oxygen

[2] BOD = ppm 5-day Biochemical oxygen demand

pletely devoid of odor. As of January 24, 1962, a BOD of 910 ppm was reported, a significantly lower value for this period than noted in the earlier years.

In conclusion, it is possible to effect rather dramatic results with a treated lagoon system. This should be as true if not more so in areas not subjected to such severe winters and where the waste water can be so diverted to maintain higher lagooned water temperatures over an extended period of time. Although our company has been able to discharge factory waste water before a practical maximum BOD reduction has been obtained, the loading has been in the range of 3.5 to 4 pounds of 5-day BOD per ton of beets sliced. This is certainly the maximum that could be realized under proper conditions and with sufficient lagoon capacity.