AN INVESTIGATION OF SUGAR MILL EFFLUENTS

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Abstract

A sugar mill was investigated to obtain information on the effluents it produced. It was found that it produced three different water-borne effluents, all of which contained organic materials, sugar, and small amounts of other substances.

One of the mill effluents, the condenser water, was recycled through a cooling pond and the variations in the concentration of dissolved oxygen in the cooling pond were also investigated.

Introduction

Investigations of sugar mill effluents have been carried out in the past in other countries, for example by Keller et al[1,2] in Louisiana, but no similar work has been carried out in South Africa.

This paper describes an investigation into the effluents produced by the sugar mill of Doornkop Industries Limited. It was carried out in co-operation with the National Institute of Water Research of the CSIR as part of an integrated investigation into the water quality of the river below the mill. However, the investigation into the water quality of the river is not yet complete and this paper describes only the work done on the mill.

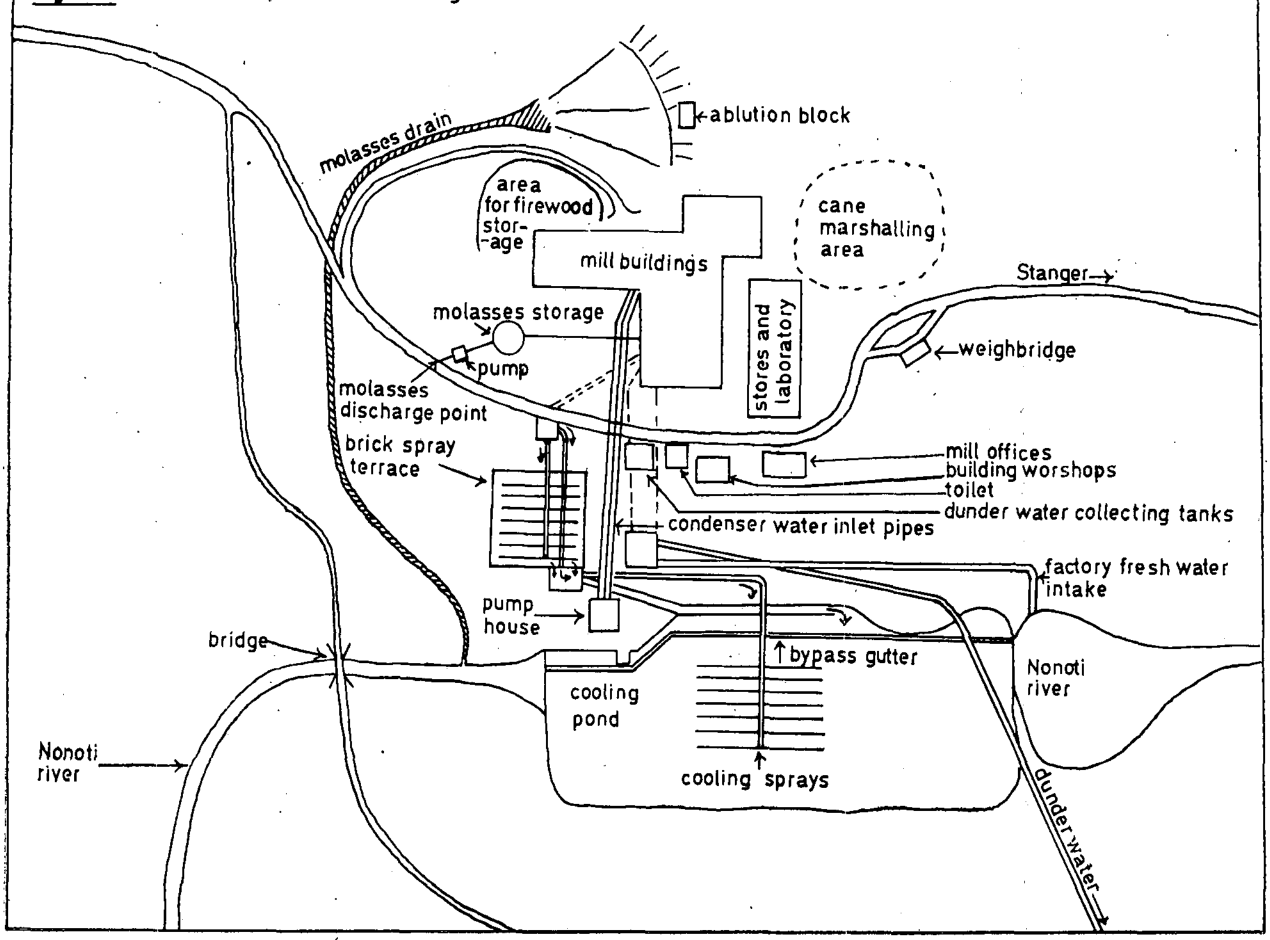
The mill effluents

At the start of the investigation little detailed knowledge was available about the composition of sugar mill effluents or where they originated in the milling process. The first step therefore involved the location and analysis of all the effluents.

There were found to be three effluents; the condenser water, the dunder water and a small open drain, originating behind the mill, called the scum-yard drain.

The condenser water was made up of the effluents from the six condensers on the vacuum pans, the two condensers on the evaporators and the two on the vacuum filters. The dunder water was made up of the effluent calandria condensate used for internal washing of the mill, and the scum-yard drain con-

Figure 1 Plan of the mill and its surroundings



sisted of water draining from a low lying area behind the mill, adjacent to an area used for rubbish disposal, the so-called scum-yard. In time of rain this drain received leachings from spillings of filter cake, which was loaded into railway trucks in this area (Figure 1).

The mill evaporates on average 29,000 lb. of water per hour from the final effects of the evaporators and 11,000 lb. from the pan station.

The flow of condenser water leaving the factory was measured at 10 cusecs. At the time of the survey the condenser water was cooled by being passed through two sets of cooling sprays under gravity feed, one situated on a brick terrace on one bank of the Nonoti river, near which the mill is built, and the other in a cooling pond built across the river itself. The cooled water from both sets of sprays was collected in the cooling pond and pumped back to the mill for re-use. The construction of the pond was such that the Nonoti flowed through it, with the exception of approximately one cusec which was carried round it in a metal gutter for the benefit of river users below the mill.

Analysis of the condenser water (Tables 1 and 2) showed that it contained organic matter identifiable by the Biochemical and Chemical Oxygen Demand tests (BOD and COD) and smaller amounts of sugar identifiable by the α-napthol sulphuric acid test. Since analysis of the river water upstream of the mill showed no sugar and negligible BOD, that

TABLE 1
Summary of Analyses of Condenser Water

Parameter*	Range
pH	6.51–7.90
Total solids ppm	89–136
Total dissolved solids ppm	96–139
Suspended solids ppm	0–13
COD ppm	0–96.05
Kjeldahl nitrogen ppm	0–3.24
Nitrate ppm	0–1.10
Phosphate ppm	0–1.0
Oil ppm	0–5.2
Sugar ppm (α–napthol test)	1–4

*The analytical methods used are set forth in the appendix

TABLE 2
Biochemical Oxygen Demand (BOD) of Condenser Water Leaving the Mill and of Cooling Pond Water Taken During a 24 Hour Monitoring Survey

Time	BOD Condenser Water (P.P.M.)	BOD Cooling Pond Water (P.P.M.)
11.00 a.m.	172	162
1.00 p.m.	263	182
3.00 p.m.	207	170
5.00 p.m.	250	395
7.00 p.m.	312	225
9.00 p.m.	208	170
11.00 p.m.	157	168
1.00 a.m.	164	93
3.00 a.m.	217	83
5.00 a.m.	147	143
7.00 a.m.	163	171
9.00 a.m.	51	110

found in the condenser water must have been added by the mill. The only way in which this could have occurred was by entrainment in the evaporators and vacuum pans.

The large difference between the COD and the value found by the α-napthol test shows that the largest fraction of the contamination in the cooling pond is composed of the breakdown products of sucrose, which do not give colour with the α-napthol test.

The second effluent, the dunder water, was collected in a network of floor drains and piped to two concrete tanks outside the mill. A small flotation oil trap was installed between the mill and the collecting tanks, from which trapped oil was skimmed off manually and burned. The dunder water was pumped on to cane fields near the mill and used for furrow irrigation. The dunder water exhibited higher concentrations of sugar and organic materials than did the condenser water, and also a higher concentration of Kjeldahl nitrogen (Table 3).

Analysis of the scum-yard drain (Table 4), which flowed into the river just below the weir of the cooling pond indicated that it was high in organic matter and sugar. A bacteriological analysis showed it to contain organisms usually found in untreated sewage.

Variations of oxygen concentration in the cooling pond

During the investigation of the mill, the water in the cooling pond was periodically tested for dissolved oxygen, both during working hours and during the weekend shutdowns (Table 5). A few weeks after the beginning of the milling season it was found that if the concentration of dissolved oxy-

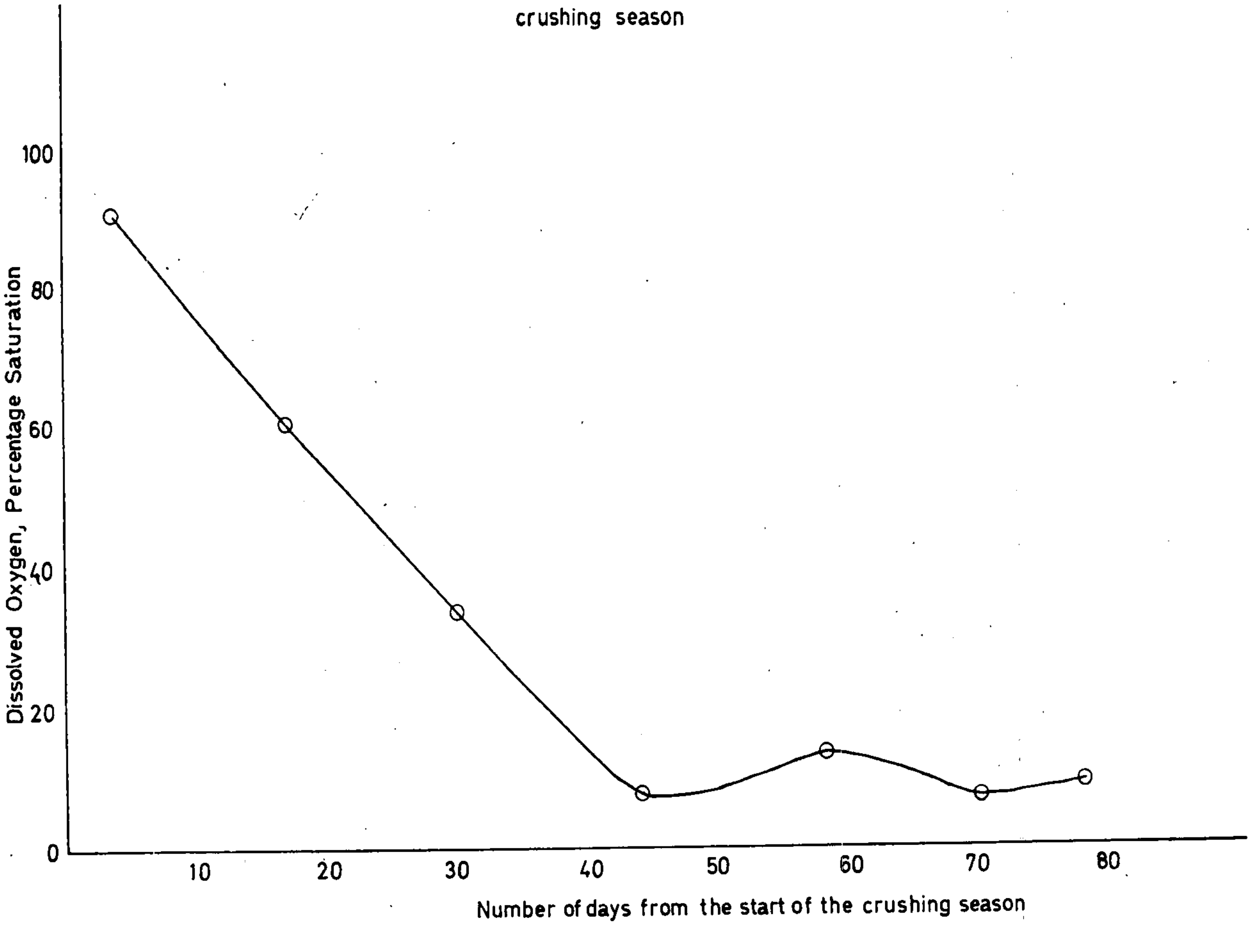
TABLE 3
Summary of Analyses of Dunder Water

Parameter	Range
pH	4.18–6.50
Total solids ppm	619–2231
Total dissolved solids ppm	504–1719
Suspended solids ppm	115–442
COD ppm	358–1432
Kjeldahl nitrogen	4.10–19.21
Nitrate ppm	0–8.0
Phosphate ppm	0–9.1
Oil ppm	9.6–68.6
Sugar ppm (α–napthol test)	90–300

TABLE 4
Summary of Analyses Done on Scum-Yard Drain

Parameter	Range
pH	6.35–7.68
Total solids ppm	365–2097
Total dissolved solids ppm	339–2016
Suspended solids ppm	0–26
COD ppm	86.7–900.0
Kjeldahl nitrogen ppm	0–4.10
Nitrate ppm	0–1.25
Phosphate ppm	1.25–5.0
Oil ppm	0–32.4
Sugar ppm (α–napthol test)	0–240

Figure 2 Curve of Dissolved Oxygen as measured during the weekend shutdown period vs. time from the start of the crushing season



gen in the cooling pond during successive weekend shutdowns was plotted against time from the start of the crushing season the curve shown in Figure 2 resulted.

For the first six weeks the oxygen concentration in the cooling pond as measured at the weekend decreased regularly with time. Thereafter it levelled off at about 1 ppm (±10% saturation). During working hours, however, the concentration of dissolved oxygen was found to be much higher, even though the temperature of the pond was also higher and the saturation level of oxygen therefore lower.

To investigate the changes involved the pond water was tested for dissolved oxygen during the whole of two successive weekend shutdown periods, ranging from before the condenser water flow through the cooling sprays was stopped to after it was re-started. It was found that a very rapid drop in the concentration of the dissolved oxygen took place when the water flow through the sprays was shut off; it then levelled off at about one ppm for the remainder of the shutdown period (these tests were conducted respectively at ten and eleven weeks after the start of the crushing season); when the flow of water through the sprays re-commenced it rose very rapidly to its former level (Figures 3 and 4).

The cooling sprays were therefore seen to have a very strong oxygenating effect upon the water of the cooling pond. The significance of the weekend tests is that they reflect the dissolved oxygen concentration when the oxygenating effect of the sprays

TABLE 5
Dissolved oxygen and temperature measurements carried out on the Cooling Pond

Date	Dam Tempera-ature °C	Dissolved Oxygen P.P.M.	Dissolved Oxygen % Satur-dation	Remarks
20.4.67	21.7	6.87	78.00	Samples taken before start of crushing season
21.4 67	20 0	8.20	88.50	
22.4 67	19.0	8.59	91.14	
23.4 67	19.8	8.54	90.08	
24.4.67	20.5	8.20	91.01	
25.4.67	31.5	7.33	99.04	Start of crushing season
26 4.67	32 0	7.28	98.35	
3.5.67	31.5	6.24	84.40	
8 5.67	21.8	5.31	60.32	Shutdown
9 5.67	33.3	5.66	78.56	
10 5.67	32.5	5 09	69.98	
11 5.67	33.7	5.18	71.94	
18 5 67	32.2	5.65	76.40	
19.5 67	34.0	4.70	65.40	
21.5 67	20.5	3 05	33.90	Shutdown
22.5.67	30.0	4.49	59.05	
23.5.67	32.0	4.39	59.30	
24.5.67	34 0	5.07	70.46	
29.5.67	33.5	4.69	65.20	
30.5.67	34.5	4.80	67.66	
1.6.67	32.5	4.80	65.82	
2.6.67	30.0	5.69	74.98	
4 6.67	17.50	0.50	7.60	Shutdown
15.6.67	34.0	5.35	74.35	
16.6.67	33.1	5.14	70.41	
18.6.67	21.0	1.20	13.30	Shutdown
2.7.67	21.0	0.50	5.5	Shutdown
10.7.67	21.0	0.65	7.22	Shutdown

Figure 3 Curves of dissolved oxygen and temperature in the cooling pond vs. time during the weekend shutdown period 1-2 July 1967

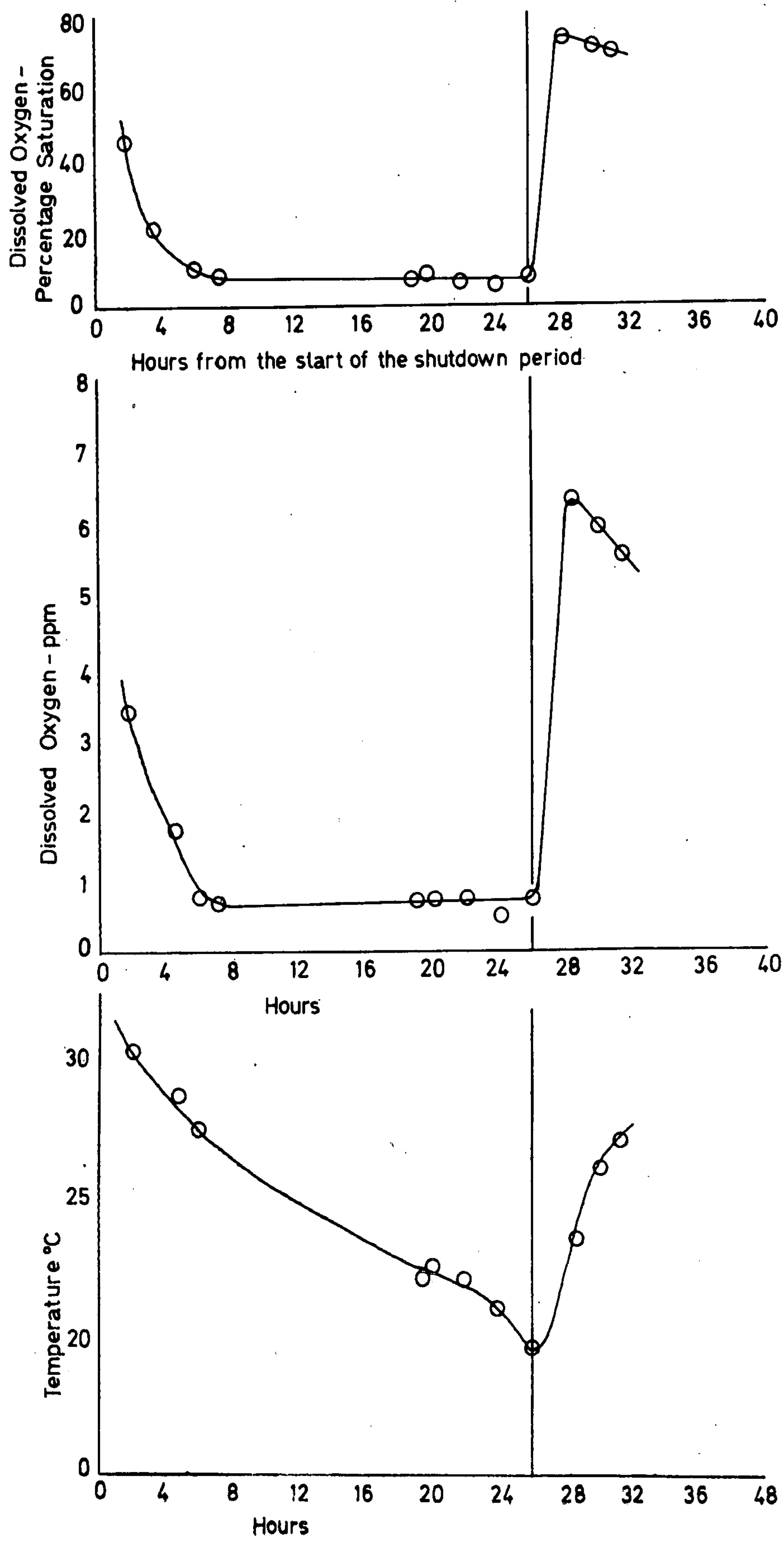
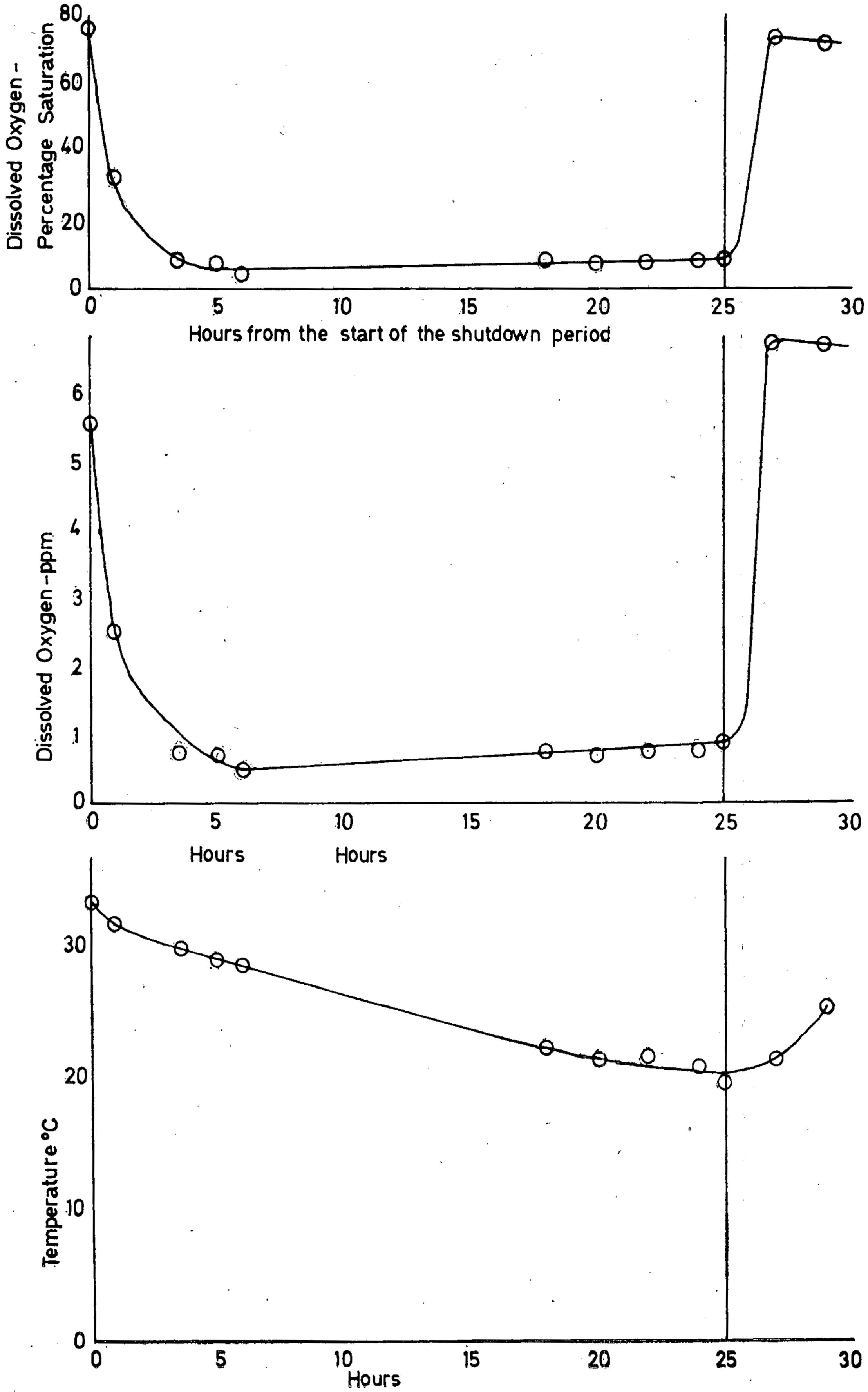


Figure 4 Curves of dissolved oxygen and temperature in the cooling pond vs. time during the weekend shutdown period 9-10 July 1967



is absent. Since under these conditions the concentration of dissolved oxygen in the pond is the result of a dynamic equilibrium between oxygen uptake and oxygen demand, and since oxygen uptake is a function of the surface area of the pond, which remains constant, the steadily decreasing oxygen concentration is an indication of steadily increasing oxygen demand.

The following hypothesis was put forward in explanation:

A mathematical model (Kemp, P. H. 1968 — unpublished) showed that in a system such as the condenser water cooling system at this mill, given a constant rate of entrainment and a constant flow of water through the system, the level of dissolved organic material in the system would tend towards an equilibrium value. The flow of river water through the pond for most of the period of investigation was approximately three cusecs, and the model showed that under these conditions equilibrium would have been reached in about six hours.

Oxygen demand is caused by biological action on organic materials and if dissolved organic material was acting as the substrate the oxygen demand would have reached a maximum when the concentration of dissolved organic matter did so, that is in about six hours plus a short period to allow the microbiota to build up. The fact that it took six weeks to do so suggested that not soluble but insoluble matter was acting as the substrate.

If this was in fact the case the observed almost linear drop in dissolved oxygen as measured at the weekends could have resulted from a deposit of insoluble organic matter spreading over the bottom of the pond until it completely covered it. The number of aerobically respiring organisms living on or near the surface of the deposit would then stabilise, and the oxygen demand would stabilise in consequence. However, the very rapid drop in the concentration of dissolved oxygen which was observed when the flow of water through the cooling sprays was shut off gave rise to doubt whether such a drop measured at the surface of the pond could be transmitted sufficiently rapidly from a bottom layer by the mechanism of simple diffusion. The speed of the drop indicated that biological activity in the body of the water might be the cause, which would invalidate the hypothesis that the oxygen demand was caused by the layer of organic material on the bottom.

If the oxygen demand was in fact located in the body of the water rather than on the bottom, the water a short distance below the surface would be anaerobic. To determine whether this was the case, and therefore whether the oxygen demand originated in the body of the water or on the bottom, samples were withdrawn from selected depths in the pond during a weekend shutdown period by means of the apparatus in Figure 5.

The aspirator was first rinsed, then completely filled, and water was drawn through before any was taken for a sample so that the dissolved oxygen status of the water was not altered. Dissolved oxygen and temperature were measured. The water below the surface was not found to be anaerobic, and no gradient in either dissolved oxygen or temperature between the surface and the bottom of the pond was found (Table 6). The lack of large temperature differences indicated the presence of convection currents in the pond; since the temperatures were measured with a mercury thermometer accurate to 0.2°C and not with a thermocouple the small temperature differences associated with convection currents in water were not detectable.

Figure 5

Apparatus used for determining dissolved oxygen at selected depths in the cooling pond

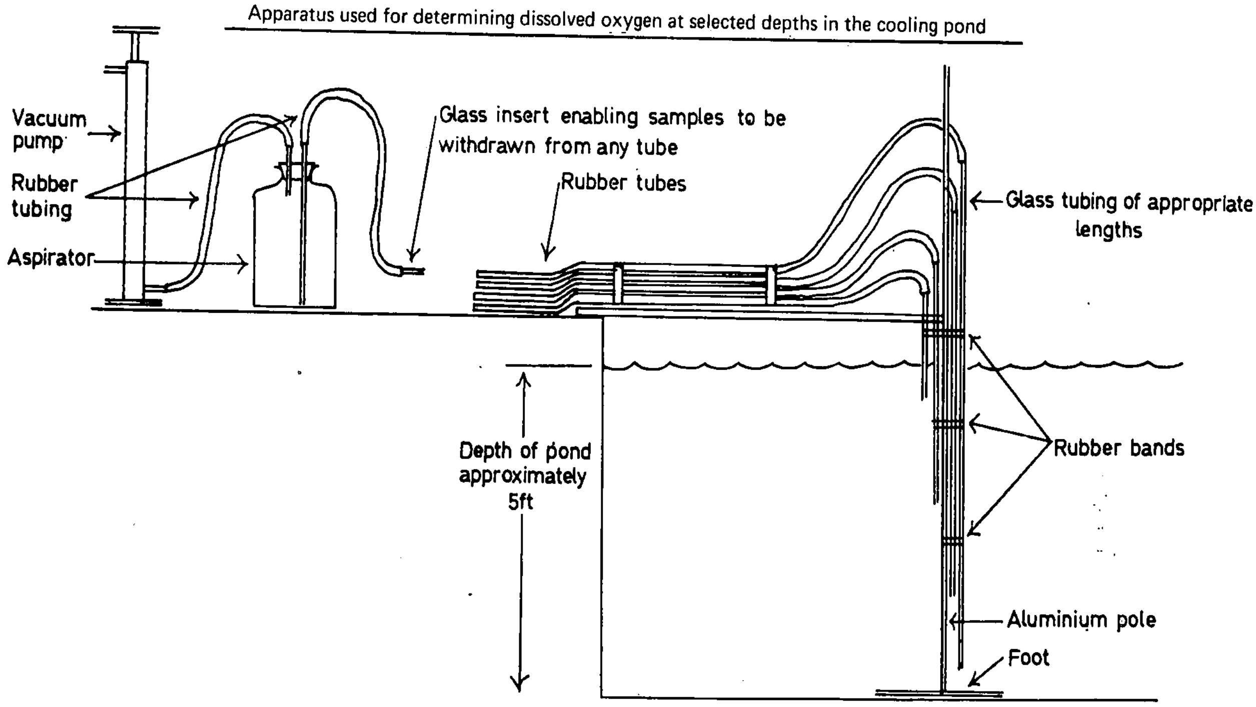


TABLE 6
Dissolved Oxygen and Temperature Measurements Made on Water Taken from Various Depths in the Cooling Pond During a Weekend Shutdown

Time	Depth	Dissolved Oxygen (ppm)	Temperature °C	Time	Depth	Dissolved Oxygen (ppm)	Temperature °C
SATURDAY							
4.00 pm	1	2.10	Not measured	12.00 pm	1	1.02	Not measured
	2	3.10	,,		2	1.10	,,
	3	2.65	,,		3	1.28	,,
	4	3.00	,,		4	1.30	,,
				SUNDAY			
4.30 pm	1	2.70	35.40	1.00 am	1	1.00	,,
	2	3.60	34.40		2	1.20	,,
	3	2.60	34.40		3	1.60	,,
	4	1.55	35.25		4	1.02	,,
5.00 pm	1	2.50	34.9	2.00 am	1	1.10	,,
	2	1.0	34.9		2	0.80	,,
	3	1.25	34.9		3	1.18	,,
	4	2.20	34.20		4	1.07	,,
5.45 pm	1	1.94	34.20	3.00 am	1	1.10	,,
	2	1.76	34.60		2	1.30	,,
	3	1.60	34.60		3	1.15	,,
	4	1.82	32.80		4	1.05	,,
6.15 pm	1	1.75	32.20	4.00 am	1	1.05	,,
	2	1.90	34.75		2	Not sampled	,,
	3	1.80	33.60		3	1.0	,,
	4	1.70	33.90		4	1.1	,,
7.00 pm	1	1.24	31.60	5.00 am	1	0.65	31.0
	2	1.01	33.00		2	0.70	32.0
	3	1.00	33.30		3	0.80	31.8
	4	1.00	33.60		4	1.0	31.6
8.00 pm	1	0.83	33.30	6.00 am	1	1.45	30.6
	2	0.85	32.40		2	1.30	30.8
	3	1.00	32.80		3	1.25	31.0
	4	1.15	33.20		4	1.45	31.0
10.00 pm	1	1.00	31.60	7.00 am	1	1.00	30.4
	2	1.20	31.70		2	1.20	30.7
	3	1.25	31.00		3	1.20	30.7
	4	0.99	31.80		4	1.13	31.3
11.00 pm	1	1.20	Not measured				
	2	1.23	,,				
	3	2.17	,,				
	4	1.40	,,				

Depths below the surface: 1—6 inches
2—2 feet
3—4 feet
4—6 inches above the bottom

The presence of dissolved oxygen in the body of the water at approximately the same concentration as on the surface suggests that the main oxygen demand is not in the body of the water; and the convection currents provide a mechanism by which the oxygen demand of a bottom layer could be transmitted to the surface with sufficient rapidity to account for the observed oxygen drop when the cooling sprays are shut off.

These results therefore suggest that it is the organic matter on the bottom of the pond rather than that dissolved and suspended in the body of the water which exerts the primary influence on the dissolved oxygen status of the pond.

This work could not be extended since the milling season ended shortly after the last experiment was carried out and the layout of the mill was changed the following year in such a way that this pond is no longer used. A new concrete dam has been built for the same purpose and it is hoped to undertake further experiments on this in the future.

Conclusions

The sugar mill investigated produces three water borne effluents; the condenser water, the dunder water and the scum-yard drain. All contain organic matter, sugar and small quantities of other substances. The sugar in the condenser water is derived from entrainment in the condensers in the mill; that in the dunder water from spillings in the mill, while the sugar in the scum-yard drain comes from spillings of filter cake in the area of its source.

The condenser water is recycled and collected in a cooling pond after it has been passed through cooling sprays. Evidence was found that a precipitation of organic material took place on the bottom of the pond. Measurements of dissolved oxygen in the pond show that the cooling sprays have a strong oxygenating effect upon the water in the pond.

Acknowledgements

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References

1. Keller, A. G. and Huckaby, H. K., 1960. Journal of the Water Pollution Control Federation, *32*, 7.
2. Wheeler, J. E. and Keller, A. G., 1956. Sugar Journal, *18*, 20.

Appendix

The methods used for the determination of Total Solids, Total Dissolved Solids and Suspended Solids, COD, Kjeldahl Nitrogen, Nitrate, Phosphate, BOD and Dissolved Oxygen (Azide modification of of Winkler method) were as set down in "Standard Methods for the Examination of Water and Wastewater", 12th edition, New York, 1965.

Oil was determined as follows: 500 ml samples of water were extracted for one hour in a continuous liquid — liquid extraction apparatus with redistilled petrol ether. The ether was then evaporated off from a weighed beaker on a water bath, leaving the extracted oil. The beaker was cooled in a desiccator and weighed. A blank was carried out using distilled water in place of the sample to determine the residue due to the ether.

The blank figure was subtracted from the experimental figure and the weight of oil present was calculated.

Sugar was determined by the α -napthol-sulphuric acid test. It was found that the maximum colour was obtained when the proportion of 1 ml 5% ethanolic αnapthol: 5 ml water sample: 10 ml conc. Sulphuric acid was used. The absorbence peak was found to be at 490 mμ. The standard graph was obtained using known amounts of pure sucrose solution. Distilled water blanks were used throughout.

Discussion

Mr. Barnes: Mr. Cox's work is related to a comprehensive investigation which is being conducted into sugar mill effluents and in fact, into the effect the cane sugar industry has on the quality of river waters in Natal.

The work is conducted by a team centred on the National Institute for Water Research of the C.S.I.R. in Durban and is called the Natal Rivers Research Fellowship.

The work is more extensive than that conducted by Mr. Cox and as he has indicated there is more to be done.

The sugar industry has four representatives on the working committee which controls the investigations.

In some countries special steps are taken to treat sugar factory effluents so that they are suitable for discharge into public streams and in due course we shall no doubt reach this stage.

Mr. Alexander: I believe Mr. Cox has recently investigated an anerobic fermentation dam for the disposal of sugar mill wastes at Umfolozi.

Mr. Cox: The dam has been built at Umfolozi by the mill to provide storage for an entire season's effluent, with the hope that it would stabilise and could then be discharged into the Umfolozi river during the off-crop.

But the dam filled up in six weeks and became a dynamic digesting system.

By taking samples of the inlet and outlet flow we found that the sugar content and C O D were being reduced by about 97%. This was a simple anerobic digester functioning purely on the mill waste and without the addition of any nutrients.

More work may be done on this in the coming season. At Racecourse mill in Australia a similar installation is giving satisfactory results.

Dr. Matic: It seems strange that, at Doornkop, the amount of sugar going into the river was small and yet the pollution was fairly serious for a few miles just below the mill.

Mr. Cox: These rivers are quite heavily populated with blue-green algae and some of them are capable of living saprophytically. The introduction of 5 ppm of sugar into the river enables these algae to multiply and once started they live by photosynthesis. When they die the biomass returns to the river and decomposes adding to the organic matter content of the water, and thus to the observed pollution.

Therefore the pollution caused by 5 ppm of sugar is much more than would be expected from the resulting oxygen demand of about 5 ppm. In other words it is a synergistic effect.

Mr. Allan: I was in America recently and at a symposium that was being held on effluent control I mentioned the work at Umfolozi. The trend in America is towards wide and shallow lagoons for effluent control but they agreed that deeper dams such as at Umfolozi might be more effective. It was suggested that Umfolozi finish off with shallow ponds and paddle wheels, or air bubbles, or some means to shorten the time required to recondition the water before returning it to the river.

Mr. Robinson: The lagoon on the Nonoti river has plenty of bird life despite the fact that both Doornkop and Darnall pollute the water. It would appear therefore that the river makes a good recovery between Darnall and the lagoon, a distance of about four miles.

Mr. Cox: The main factor affecting recovery in this type of river is the degree of aeration. The Nonoti river is a smallish river which flows quite quickly over a number of rapids and therefore has a high coefficient of re-aeration.

In this particular river you get total digestion of organic material in about six miles.

I only know the river below Doornkop and not below Darnall.

Small quick flowing rivers recover much more quickly than large, placid rivers.

Sugar mill effluent is organic, rather like sewage in its characteristics. Given sufficient time it will digest to carbon-dioxide and water. There is a small inorganic increment, consisting principally of potassium, which can be detected well down the river as it does not degrade.

Mr. MacGillivray: In view of what has been said about multiplication of algae, how soon does the river at Doornkop recover during the off-crop?

Mr. Cox: In this case the most significant measurement is that of the bottom fauna.

Algae are subject to many extraneous influences, for instance they do not grow well under overgrown portions of the river bank. Some live on ooze on the bottom of the river and some on rock.

Using polychaete worms as the index organisms, of the family Tubijicidae, we find that the river recovers almost entirely in the off-crop, just a very small polluted zone remaining below the mill.

Dr. Roth: Is it only sucrose that has to be digested or is there also pentose, dextrose, etc.?

Mr. Cox: We have only investigated sucrose but we are running investigations into the nutritional requirements of algae.

Mr. Lenferna: Heavy cultivation on river banks, particularly in sugarcane growing areas, is causing erosion. Since pollution is connected with dilution, if water is prevented from flowing easily into the river, and flows underground instead, pollution will increase.

In Mauritius the problem is not so bad because the river beds have a rock foundation and the rivers flow freely and clearly.

In twenty-three years I have noticed the slowing down of the flow of the Tongaat river.

Dr. Matic: Apart from pollution, work is also being carried out on silting of rivers and use of land on river banks.

The laws regarding pollution will be enforced more and more strictly until the day when failure to comply could mean the shutting down of a factory.

Mr. Jennings: I do not think there is any worry about our rivers going underground. If they flow over sand, not only will it store water but will also filter some of the impurities.

Dr. Graham (in the chair): With anerobic dams I understand that there are obnoxious odours and these would surely have to be dealt with.

Mr. Cox: We did find there was an unpleasant smell when we started at Umfolozi but it seemed to diminish as the milling season progressed. The anerobic dams produce hydrogen sulphide, methane and mercapatans.

The Americans have done a lot of work on reducing odours, one system being to have the anerobic digester with a layer of six inches to a foot of well oxygenated water flowing across the surface, thus absorbing the gases.

Mr. Jennings: We appear to be merely transferring our problem of water pollution to one of air pollution.

Mr. Cox: You can install aerobic dams which will reduce the organic content of the sugar effluent to tolerable levels.

You can also use a device called a high rate trickling filter. This has been done in America at some beet mills. The effluent is trickled through a growth of digestive organisms attached to broken up particles of stone, etc.

Both these systems function without any smell at all.

Mr. Renton: Most mills have a closed circuit condenser cooling system which in itself constitutes one of the best aerobic dams one could wish for. Might it not be possible to put our main contaminant, the floor washing, into this dam?

Mr. Cox: It could be done but a disadvantage might be the retention time in the spray pond. Unless there is an incredibly high evaporation loss there will be some overflow from the dam because of the amount of water taken into the mill as maceration water and water in cane, and this overflow is sufficient to contaminate a river, which is in fact the case at Doornkop.

Mr. Robinson: Is oil not a problem as regards pollution?

Our agriculturists complain because the dunder water that we spray on our lands contains oil.

Mr. Cox: Most mills do not put dunder water into the river and dunder water is the main source of oil contamination.

If allowed into the river it would reduce the ability of oxygen to pass over the air-water interface and therefore accentuate the problem of oxygen sag.

Oil in river water is very persistent as it is available to very few micro-organisms.