The discharging of industrial wastes into streams often results in severe pollution problems in many localities. Among the most objectionable of these wastes is the sulphite liquor from the pulp and paper industry. Many investigations have been conducted concerning the possibility of alleviating the pollutional effects of this waste. So far, no economically feasible method has been found. However, ponding and aeration of sulphite liquor before discharging it into the stream appears to effect a reduction in the pollutional strength of this waste.

The purpose of the research for which this thesis presents the results was to determine, quantitatively, the effect of ponding and aeration on the biochemical oxygen demand of sulphite liquor. The standard biochemical oxygen demand determination is considered by authorities to be an indication of the pollutional strength of a substance.

Ponding of sulphite liquor at a constant temperature appears to reduce the oxygen demand considerably. Ponding at 50°C. for ten hours resulted in a net reduction of 79 percent. The effect of temperature, during ponding, upon reduction was quite marked. As the temperature was increased the biochemical oxygen demand decreased. Thus, for a two hour ponding period at 90°C., a reduction of 85 percent was obtained.

Ponding with agitation, while somewhat more effective than straight ponding, does not appear to warrant the additional treatment. Convection currents in the warm liquor seem to provide sufficient aeration, and any further degree of aeration is not effective. A maximum reduction in oxygen demand of 50 percent at 50°C. was obtained by the agitation method. A two hour period was used.
Results indicate that aeration in a column by passing hot air countercurrent to a stream of sulphite liquor does not lower the oxygen demand below the reduction accomplished by straight ponding. In a two hour period a reduction of 30 percent in biochemical oxygen demand was obtained.

Considering all the results and the conditions under which the experiments were conducted, it appears that continued treatment by any of the above discussed methods would eventually yield a very satisfactory reduction in the oxygen demand of pulp and paper trade wastes.

Geoffrey William O'Dell

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EFFECT OF PONDING AND AERATION UPON THE BIOCHEMICAL OXYGEN DEMAND OF SULPHITE LIQUOR

by

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Acknowledgment is also made to the personnel of the Crown Willamette Paper Company at Lebanon, Oregon, who kindly supplied the sulphite liquor for the experiments.
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EFFECT OF PONDING AND AERATION UPON THE BIOCHEMICAL OXYGEN DEMAND OF SULPHITE LIQUOR

I Introduction

I-A Stream Pollution Sportsmen, conservationists, and public health officers all look upon stream pollution from different viewpoints (8). Each has a different conception of what constitutes stream pollution, depending upon the manner in which it affects him. All of these conceptions are correct with respect to their points of view. However, in all cases of stream pollution, the oxygen content of the stream is reduced, and often to such an extent that higher forms of animal life cannot exist within it.

Under such conditions, bacterial life and lower forms of animal life increase (2). The life of these minute organisms is supported by decaying organic matter which in the process of stabilization, draws dissolved oxygen from the stream, thereby lowering its oxygen content. Very often the rate at which the oxygen is taken up by decaying matter is greater than the rate of reoxygenation of the stream by aeration and higher forms of plant life. When this condition exists, the oxygen content of the stream drops so low that fish life cannot exist in it. Also, the water becomes dark and murky, and develops a pungent odor. Fungus life becomes plentiful. Tubifer worms, rat-tailed maggots and sewage flies appear.
The sources of stream pollution are quite numerous. Industrial wastes and domestic sewage are the chief sources in most rivers. Common industrial wastes are those from pulp and paper mills, canneries, packing plants, tanneries and various other industrial operations. These industries are often located near rivers for the convenience of waste disposal. The waste by-products of these industries are mostly organic in nature and undergo decomposition and oxidation in the stream. Some of these wastes are highly caustic or acid, and possess a high immediate chemical demand for oxygen. Such wastes result in an immediate serious depletion of oxygen in the stream, and consequently exert a severe pollutional load upon it. Later oxidation of these wastes is slower and takes place by bacterial action, thereby giving the stream an opportunity to maintain a reasonable amount of dissolved oxygen through aeration.

II Stream Pollution by Pulp and Paper Industry

II-A Description of Pulp and Paper Industry More than 75 percent of the total production of paper is made from wood pulp (8). The largest bulk of this is made by the digestion process in which undesirable materials in the wood are placed in solution by chemical treatment, leaving the cellulose fibers in a relatively pure state.
The woods most commonly used in the making of pulp are hemlock, spruce, cottonwood and white fir. In some communities paper is made from rags, old papers, straw and flax. The chemicals used in the digestion process are sulphur and lime (1).

Due to economic considerations, the sulphite process is the one most generally used throughout the paper industry. This process is the only one in use in Oregon, and since it is the wastes from this process that have been studied in this research, a brief description of it will be given here.

The sulphite process (3) is essentially a chemical treatment, or digestion, of chipped wood under pressure and at an elevated temperature, in a solution of sulphurous acid and calcium acid sulphite. These chemicals do not appreciably alter the cellulose fibers of the wood under controlled conditions. They react with the lignin, polysaccharids and resins to place them in solution in the liquor. The digestion is carried on in brick lined digesters, heated by direct admission of stream to the charge within. At the end of a ten to twenty hour digestion or cooking period, the fibers and liquor are forced by pressure from the digester into a receptor called the blow pit. Here the liquor is drained off through the perforated or false bottoms of the blow pit. The
residual liquor is removed from the fibers by an extended washing operation in the pit. This liquor is the waste sulphite liquor which is usually disposed of by being emptied in the nearby river or stream. The pulp is then carried from the blow pit by water, through a series of screens, upon which uncooked material, dirt, grit, and oversized particles are separated. Beyond the screens the pulp is freed from a large portion of the water by a continuous filter or "decker". Here the pulp is gathered into laps and transferred in this form to the paper making process proper.

Briefly, the paper making process may be considered a bleaching, beating and laying of the fibers into a sheet. The laying of the sheet is accomplished upon a paper machine by extraction of the water upon a wire so that a fiber mat results. This mat is dried and pressed into sheets by the subsequent operations.

The above described process results in four typical wastes. These are classified as sulphite liquor, as mentioned above, sulphite mill white water, spent bleach liquor, and paper machine white water. Due to the fact that white water wastes may be recycled and used continuously, the disposal of these does not present a difficult problem. While the disposal of all wastes is a problem, by far the most serious problem is that of the economic
disposal of sulphite liquor.

**II-B Pollutional Strength of Wastes** The amount of white water waste discarded into the streams varies in volume and fiber content with almost every mill. The fiber content of this waste determines its pollutional strength (3). The pollutional strength of white water, however, is not very high, due to the slow decomposition of the fibers. It does not present a serious problem unless, during periods of low water it collects in sludge banks and begins to decompose. The oxygen demand of white water wastes approximates that of domestic sewage.

Bleaching and dyeing wastes also have an oxygen demand in the stream (7). This demand is not relatively high, however, and the disposal of these wastes does not constitute a serious problem.

The disposing of sulphite liquor in a manner which is economically feasible and which will not impose a heavy pollutional load on the stream into which it is emptied is a major problem of the pulp and paper industry.

Sulphite liquor is composed of a large number of compounds (8) (1). It contains many organic chemical compounds such as sugar, alcohol, aldehyde, cymene, acetic and formic acids (1). Also it contains free and loosely combined sulphur dioxide and calcium acid sulphite. Sulphite liquor is quite acid in nature, having a pH value around 5.5. The specific gravity of the substance varies from
1.03 to 1.05, with a total solids content of from 8 to 12 percent. These properties all vary with the different mills. Approximately all but 1 percent of the dry sulphite liquor is combustible. The heating value of dry sulphite liquor solids averages 8000 B.t.u. per pound.

Over 50 percent of the dry weight of the wood used in making pulp is discarded as waste in the sulphite liquor. For every ton of paper produced, about 2000 gallons of waste sulphite liquor is discarded into the streams. This liquor has a high immediate demand for oxygen, and also a high demand for complete stabilization. The oxygen demand of any substance is measured in parts of oxygen required per million parts of the substance, and is referred to as the biochemical oxygen demand (9) of the substance. Biochemical oxygen demand is quite definite for complete stabilization of a particular substance, but it is not necessarily referred to in this sense. It is mostly referred to as the amount of oxygen a substance will require in a certain amount of time, during the process of stabilization. The total oxygen demand of sulphite liquor is variable, depending upon its concentration and composition. An average sample of sulphite liquor has a 5 day oxygen demand of approximately 10,000 p.p.m. and a 20 day oxygen demand of 20,000 p.p.m. (8). Compared with domestic sewage which may average about 250 p.p.m. (2) for 5 days
the oxygen demand of sulphite liquor is very high.

II-C Remedies for Pollutional Effects of Wastes
The industries have carried on research, seeking possible means of utilization of sulphite liquor such that they may economically convert it into valuable by-products (1). It has been demonstrated that such by-products as sulphite alcohol, glue, core-binder, road binder, briquetting material for coal dust, tanning extracts and many other similar articles of commerce can be obtained from waste liquor, but a few mills can supply the entire present demand for some of these quantities. Recovery processes for these commodities fail in competition with industries using different sources of raw material and methods of production. Thus, utilization of sulphite liquor as a source of saleable by-products does not appear to be an economic solution of the pollution problem.

Utilization of the fuel value of this waste, which amounts to approximately 8000 B.t.u. per pound of the recovered concentrate (5), seems promising for economically reducing stream pollution. However, recent experiments have shown that more efficient methods are needed for draining and washing the pulp, and subsequent evaporation of the liquor to a consistency satisfactory for burning.

The pollutional strength of sulphite liquor may be reduced if its oxygen demand is partially satisfied before
it is emptied into the river.

Reduction in oxygen demand may be accomplished by chemical means. The Howard Process (4) is a fractional precipitation process which uses a caustic solution of lime, in precipitating compounds from sulphite liquor. The biochemical oxygen demand of the effluent is reduced 75 percent and no toxicity results. The effluent carbohydrates appear to be highly stable. The economic feasibility of this process, however, is as yet undetermined. The Frank and Bruch Process (7), which includes neutralization and settling with the use of lime, alum, and organic materials has been discarded since it was economically unfeasible.

The fact that sulphite liquor exerts a considerable demand for oxygen when discharged into the stream, served as an indication that this demand might be reduced by aeration of the liquor before it entered the stream. Experiments carried on at the State Laboratory of Hygiene in Wisconsin (2), indicate that its oxygen demand could be reduced approximately 50 percent by forcing air into it through the pores of a bass wood block. This experiment seemed to confirm the opinion that a large part of the initial demand is due to direct chemical oxidation of the unstable constituents. This initial oxygen demand is then followed by one of more gradual deoxygenation of the
stream. The immediate oxygen demand of the waste is undoubtedly due to the oxidation of free and loosely combined sulphur dioxide in the spent liquor. The oxygen demand following the initial requirement is probably due to the stabilization, under aerobic conditions, of the carbonaceous organic matter in the waste, and secondly, due to oxidation of a small amount of nitrogenous matter in the waste.

Investigations regarding the ponding and aeration of sulphite liquor were begun in 1926 on the Flambeau River at Park Falls, Wisconsin (1). A sulphite waste liquor settling pond and a cascade dam were built to study their effect in reducing the oxygen demand of this waste. The volume of this reservoir was such that, with an average daily discharge of 73,000 gallons of sulphite liquor and 128,500 gallons of waste water, a retention period of slightly over two days was provided for the liquor. Thus, it was given ample time to settle and take up oxygen from the air, thereby supplying its immediate demand.

Oxygen demand tests were made of the ponded liquor according to the dilution method described in "Standard Methods of Water Analysis". The results obtained indicated that the oxygen demand for periods of from 12 hours to 5 days was reduced from 76 to 92 percent, by ponding and aeration. It is believed that the initial oxygen demand
is materially satisfied within two or three days during the settling period. The somewhat slower second stage oxidation, referred to above, seems but slightly accelerated by cascading the liquor over the reservoir dam.

The continued high efficiency of the pond appeared improbable, however, due to the stratification and concentration of solids under the surface. Higher oxygen demands were found in samples taken at greater depths.

At Rothschild, Wisconsin, aeration experiments on sulphite liquor were conducted, using a spray device, called the Bassler air and gas scrubber. Tests indicated a reduction of from 34 to 60 percent in oxygen demand for one to five day periods.

III Laboratory Determinations Indicating Pollution

III-A Biochemical Oxygen Demand Tests The biochemical oxygen demand test has been considered by authorities for many years as a method for indicating the pollutional strength of wastes discharged into rivers and other bodies of water. The determination of dissolved oxygen present in diluted samples of the waste, over several periods of time, indicate the demand of the waste for oxygen, and the rate at which it absorbs oxygen, during the process of its stabilization (11).
The Winkler method (9) for determination of dissolved oxygen, or modifications of this method where necessary, is the common procedure that is used. This process depends upon the formation of a precipitate of manganous hydroxide in a glass stoppered bottle, completely filled with the water under examination. The oxygen dissolved in the water is readily absorbed by the manganous hydroxide, forming a higher oxide of uncertain chemical composition. This compound, on acidification in the presence of a soluble iodide, releases iodine in quantity stoichiometrically equivalent to the oxygen content of the sample. The liberated iodine is then titrated with a standard solution of sodium thiosulphate in the usual manner. The laboratory setup is shown in Figure D.

Various modifications of this general procedure are available for counteracting the effect of interfering substances (9). For sulphite liquor solutions of rather high concentrations, the Alkaline Hypo-chlorite modification is recommended. However, Mr. L.F. Warrick, state sanitary engineer, Wisconsin, in a private communication, August 15, 1933 to the Chemical Engineering Department of Oregon State College, states that with dilutions of 1:4000 and greater, the above modification proposed by Mr. E.J. Theriault, was found to be unnecessary, and that consistent results might be obtained without its use. Since all dilutions made for
this research were 1:5000 and over, the unmodified Winkler process was used in all dissolved oxygen determinations. In accordance with Mr. Warrick's predictions, quite consistent results were obtained with the Winkler method.

The choice of dilution water for this project was derived from a procedure recommended by Mr. E.J. Theriault (10). In preparation of this water, a buffer solution of potassium acid phosphate and sodium hydroxide is used. As the pH range of natural waters is from 6.4 to 8.0, an average pH value of 7.2 is used in the buffer. This pH value is obtained by a variation of the sodium hydroxide content of the buffer, with colorimetric or electrometric standardization. As the biochemical oxygen demand test depends upon the symbiotic activity of bacteria and plankton (9), it is necessary to insure the presence of both of these classes of organisms in the dilution water. This precaution is of particular importance in the examination of industrial wastes which have been boiled or which possess a high degree of causticity or acidity. In order to insure the presence of these organisms, it is necessary to seed the dilution water with water or sewage already containing them. River water is especially recommended and was used in connection with all dilutions herein described. Saturation of the dilution water with air was insured by bubbling air through it for six hours. It was then allowed
to set long enough for the smallest of entrained air particles to escape.

The dilutions were prepared in a dilution tank, (Figure B) which was equipped with an indicator glass and scale. By these the desired volumes could be measured into the tank. All dilutions were made by means of a syphon, to avoid entrainment of air. A slow running, motor driven paddle was used in the tank to insure complete mixing of the sample with dilution water. With precaution against aeration, the dilution was conducted by a rubber hose into 300 ml. glass stoppered incubation bottles. Each bottle was filled to the top so that a water seal existed. The bottles were then stored in the incubation room which is shown in Figure A.

The period of incubation must be sufficiently long so that the results obtained may indicate a definite trend. E.J. Theriault (11) suggests that at least a five day period should be used, but that a greater incubation period might give more definite information. In this research no incubation was carried under five days, and the majority were carried from ten to twenty days and longer. Mr. Theriault also stated that consistent results depend upon the constancy of temperature during incubation. At 20°C a variation in temperature of 1°C, causes a change of about 5 percent in the specific rate of deoxygenation.
The seeded dilution water exerts a biochemical oxygen demand itself as well as does the waste within it (10). Therefore a simple day to day determination of dissolved oxygen will not yield a true value of the biochemical oxygen demand of a waste. It is necessary to make some quite definite allowance for this demand, or to run a blank on the dilution water over the same period of incubation. The latter method was used in all the determinations. The blank titrations and the sample titrations were plotted together on the same sheet of rectangular coordinate paper. At each ordinate, the difference between the coordinates of the blank and sample curves, represented that part of the titration equal to the oxygen used by the sample. Since the strength of the sodium thiosulphate solution was properly regulated, this difference was numerically equal to the parts of oxygen demanded per million parts of the diluted sample. The biochemical oxygen demand of the undiluted waste was then obtained by multiplying these results by the dilution factor, or the number of parts of water per part of waste, by volume. This gave the biochemical oxygen demand of the waste itself, as parts of oxygen per million parts of waste.

Several difficulties are encountered in the determination of the biochemical oxygen demand of industrial wastes. Variations in both the dilution for the biochem-
ical oxygen demand tests and the concentration of the sample introduce discrepancies which cause inconsistent results. Figure 1 shows the discrepancies encountered when the biochemical oxygen demand of a sample of sulphite liquor is calculated from different dilutions. It appears that as the dilution is increased, the determined biochemical oxygen demand also increases. Also, in the neighborhood of a one- to ten-thousand dilution a drop in oxygen demand appears to take place (see Figures 2 and 4). By way of speculation, one might attribute these peculiarities to various indefinite factors, such as the effect of pH and liquor concentration on the activities of the organisms present. It is definitely known that the rate of deoxygenation depends upon the activity of bacteria and plankton in the water. It was thought that possibly, during a longer period of incubation, the curves indicating oxygen demand would coincide. Figure 3 showing the results of an investigation of this possibility, indicates that at least to a one hundred day period, convergence does not take place. Consequently, no indication of the true oxygen demand could be derived from these tests. It was then decided to conduct a series of biochemical oxygen demand tests using sulphite liquor of different specific gravities, and making one to five thousand dilutions, as were used throughout the investigation. By correlation of the results of these
FIGURE 2. EFFECT OF DILUTION ON BIOCHEMICAL OXYGEN DEMAND
**Figure 3. Dilution Study Over Extended Period**

The graph illustrates the biochemical oxygen demand over a period of days, showing the dilution study results. The horizontal axis represents the number of days, ranging from 0 to 80, and the vertical axis represents the biochemical oxygen demand, ranging from 0 to 20,000.
FIGURE 4. EFFECT OF DILUTION ON BIOCHEMICAL OXYGEN DEMAND

1000 PARTS WATER PER PART LIQUOR
tests, it was hoped that a correction factor could be
determined which, when applied to all the tests, would
yield consistent relative values for the oxygen demands
of the samples.

Figure 5-A shows plots on logarithmic paper of the
biochemical oxygen demand of the samples against factors
which are functions of the specific gravities of the
samples. It is to be seen that the slopes of these curves
vary with the time of incubation. Consequently, slopes
were determined for different incubation periods, and the
corresponding correction factors calculated therefrom
(Figure 5-B). The specific gravity of each sample was
measured at 25°C on a Westphal, or Mohr balance. Since
the specific gravity above unity is directly proportional
to the concentration of the liquor, it was assumed that any
variation of the actual biochemical oxygen demand from the
theoretical, would be a function of this quantity. The
correction factor as is derived on the following pages was
developed on this basis.

Derivation of Equation for Correction of Biochem-
ical Oxygen Demand This correction was derived from the
fact that a plot of the quantity \((S - 1)(10000)\), where \(S\)
is the specific gravity of the sample of liquor, gives a
straight line on logarithmic paper.
FIGURE 5-A. SPECIFIC GRAVITY CORRECTION CURVE

FIGURE 5-B. CORRECTION CURVE CONSTANT
Derivation

\[ T = \text{B.O.D. of test as read from the plot of Figure 5-A.} \]
\[ C = \text{B.O.D. of control.} \]
\[ K = \text{Slope of curve B.O.D. vs.} \ (S - 1) \ (10000). \]
\[ S = \text{Specific gravity of liquor.} \]
\[ G = (S - 1) \ (10000). \]

The correction as seen from Figure 5-A =

\[ AB = AE - CD. \]

\( K = \text{slope of line} = \frac{AB}{CB} \)
\[ AB = K(CB) \]
\[ CB = G \text{ control} - G \text{ sample} = Gc - Gt \]
\[ AB = K(Gc - Gt) = \text{amount of correction}. \]
\[ \text{Corrected B.O.D.} = K(Gc - Gt) + T. \]

Figure 5-B shows the variation of \( K \) with the period of incubation. The value of \( K \) to be used is determined from this curve.
Example of the Use of the Correction

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On Figure 5-A, read off biochemical oxygen demand from the specific gravity factor for each test. Use this value of the B.O.D. in the derived correction equation.

Calculations

No. 2. \[ 6800 + 30.7 (230 - 184) = 8045 \]
No. 3. \[ 5300 + 30.7 (230 - 143) = 7970 \]
No. 4. \[ 3900 + 30.7 (230 - 93) = 8110 \]
No. 5. \[ 2750 + 30.7 (230 - 59) = 8000 \]
No. 6. \[ 1650 + 30.7 (230 - 31) = 7760 \]
**IV  Effect of Ponding and Aeration on the Biochemical Oxygen Demand of Sulphite Liquor**

**IV-A  Introduction**  As was previously discussed under section II, ponding and aeration of sulphite liquor effects a considerable reduction in its biochemical oxygen demand. Because of the economic feasibility of this treatment, it was deemed worthwhile to make a study of ponding and aeration with respect to several variables which might affect its efficiency.

**IV-B  Variables**  The period of ponding, the temperature, and the amount of aeration were considered to be the most important variables affecting this treatment, and to these the study was confined.

**IV-C  Ponding**  The ponding experiments were conducted in two ways. In the first test the temperature was held constant, with the time of ponding variable. In the second test, the period of ponding was held constant while the temperature was varied.

The apparatus used in the first test consisted of a large evaporating dish in which two liters of the sulphite liquor were placed. The desired temperature, $50^\circ C$, was attained by placing the dish in a water bath upon an electric plate, and was held constant by manual operation. The duration of the ponding was ten hours, with samples
being taken at the beginning and every two hours thereafter. Biochemical oxygen demand determinations were made for each sample, the first one being taken as the control. The tests were carried out for a twenty day period. The specific gravity of each sample at the time of drawing was carefully measured at 25°C with a Westphal balance. Figure C-2 is a photograph of the apparatus as it was set up. Figure 6 is a plot of the corrected biochemical oxygen demand against the days of incubation. This plot shows the twenty day biochemical oxygen demand of each sample relative to that of the control sample. Figure 7 is a plot showing the biochemical oxygen demand for several incubation periods against the hours of ponding. Figure 8 shows the percent reduction in oxygen demand for any incubation period plotted against the hours of ponding. Both Figures 7 and 8 indicate that the period of ponding up to a certain limit effects a material reduction in the oxygen demand of the waste. It is apparent from these plots that at the temperature of this test a ponding period of over ten hours would not have resulted in much greater reduction of the oxygen demand. The greatest reduction at this temperature is obtained between 2 and 8 hours of ponding. Apparently the average maximum reduction obtainable under these conditions is about 79 percent.
Figure 6. Effect of Ponding on Biochemical Oxygen Demand

**Note.** Values corrected for specific gravity.
Figure 7. Effect of ponding period on biochemical oxygen demand.
FIGURE 8. EFFECT OF PONDING PERIOD ON REDUCTION OF BIOCHEMICAL OXYGEN DEMAND

POINTS FOR THIS CURVE WERE TAKEN FROM FIGURE 7.
The apparatus used for the second ponding test was the same as that used for the first. The ponding period was held constant for each test, which lasted two hours. The tests were made at 26°C, 50°C, 70°C, and 90°C. Biological oxygen demand tests were made of samples taken at the end of each ponding period. An unponded sample of the waste was used as a control. The incubation period for samples taken in this test was five days. A twenty day period would have been more desirable, but for this test it was not convenient to extend the period that long. As in the first test, an accurate record of the specific gravity was kept.

Figure 9 shows the five day biochemical oxygen demands of the samples from the different tests. This figure shows that the higher the temperature of the liquor during ponding, the lower will be its biochemical oxygen demand. Figure 10, is a plot of the oxygen demand for different days of incubation against the temperature of the liquor during ponding. The curves in this figure show the general trend of the effects of temperature variation on the biochemical oxygen demand of sulphite liquor. These results, however, are only indicative of the effects within the limits of the experiment. The percent reduction in biochemical oxygen demand relative to the temperature maintained during the ponding period is shown in Figure 11. The
points for this curve were calculated from points taken from the curves of Figure 10. The curve of Figure 11, therefore, indicates only a general trend of the results of temperature variation. It indicates that by ponding for two hours at various temperatures, from 25°C to 90°C, reductions of from 40 to 85 percent in biochemical oxygen demand may be attained.

**IV-D Aeration** Aeration as is used in this report refers to mechanical agitation of the sulphite liquor so that its whole volume comes more fully in contact with the air. This offers the liquor a chance to absorb oxygen more readily since the unsaturated portions of it are continuously being exposed to the air. Aeration was accomplished by agitating the liquor with a mechanical stirring device as is shown in the photograph, Figure C-3, and also by means of passing air counter-current through the liquor in a column. A photograph of the column is shown in Figure C-1.

The purpose of the first aeration experiment was to determine the effect of varying the amount of agitation on the biochemical oxygen demand of sulphite liquor. A fixed volume of sulphite liquor was placed in a two-liter beaker. The liquor was maintained at 50°C on a hot water bath. It was agitated for a period of two hours with a motor-driven propeller, the speed of which could be

Figure 9. Ponding with Temperature Variable.
FIGURE 10. EFFECT OF TEMPERATURE ON BIOCHEMICAL OXYGEN DEMAND FOR DIFFERENT INCUBATION PERIODS
FIGURE II. EFFECT OF TEMPERATURE OF PONDING ON BIOCHEMICAL OXYGEN DEMAND
regulated. Samples for measurement of biochemical oxygen demand were taken at the end of each test. A control sample was taken at the beginning of the first test. The degree of agitation was measured by the revolutions per minute of the propeller. The tests were run from zero agitation to five hundred revolutions per minute.

The respective twenty day biochemical oxygen demands of the different tests are shown in Figure 12. No definite effect of aeration is to be noted by these curves. Figure 13 shows the percent reduction in oxygen demand with respect to the degree of agitation. Here again nothing can be said definitely, but it does seem that agitation under the conditions of the test did not aid materially in reducing the biochemical oxygen demand of the waste. A greater reduction is obtained at two hundred revolutions per minute than at five hundred. However, the greatest percent reduction due to agitation is not appreciably greater than the percent reduction by straight ponding, or zero revolutions per minute. This is probably due to the fact that convection currents within the warmed liquor result in aeration equivalent to the rate at which the liquor can absorb oxygen.

The second aeration experiment was to determine the effect of bubbling hot air up a column counter-current to a stream of sulphite liquor. A definite volume of liquor was
FIGURE 12. BIOCHEMICAL OXYGEN DEMAND OF AGITATED SAMPLES OVER A TWENTY DAY PERIOD
Figure 13. Reduction of biochemical oxygen demand with agitation.
used and was continually being recycled from the reservoir to the top by a pump. The air was preheated to about 100°C before entering the bottom of the column. The rate of recirculation of the liquor was 220 milliliters per minute. A photograph of the column is shown in Figure C-1. The rate of recirculation of liquor was 220 milliliters per minute. Test samples were taken every half hour for two hours. A control sample was taken at the beginning of the test. The specific gravity of each sample was carefully measured at 25°C.

Figure 14 is a plot of the corrected biochemical oxygen demand against the period of incubation. Figure 15 shows the biochemical oxygen demand against the hours of aeration. The curves in this figure indicate that the rate of change in oxygen demand is slow and that an appreciable decrease in oxygen demand would not be obtained with a larger aeration period, under the conditions of the test. Figure 16 indicates the percent reduction in biochemical oxygen demand, with respect to the period of aeration. From this figure one may infer that under the same circumstances the probable maximum reduction is around 30 percent.

V Results

V-A Ponding The results of the ponding experiments show that a material reduction of the biochemical
FIGURE 14. TWENTY DAY OXYGEN DEMANDS OF SAMPLES AERATED IN A BUBBLE COLUMN
FIGURE 15. B.O.D. V.S. AERATION

FIGURE 16. B.O.D. REDUCTION V.S. AERATION
oxygen demand of sulphite liquor may be obtained by this treatment.

Ponding at a constant temperature results in a lowering of the oxygen demand of sulphite liquor proportional to the duration of the ponding period. There is, presumably, a limit for the amount of reduction in oxygen demand that may be obtained by this method. After this limit is reached, further ponding is ineffective. Thus, in the laboratory, a 79 percent reduction in biochemical oxygen demand was obtained by ponding the sulphite liquor at 50°C, for ten hours. The curve of Figure 8 indicates that this value is near a maximum.

The results obtained with ponding at different temperatures for a constant period of time indicate that the temperature is an important factor in the percent reduction. From Figure 11, it may be seen that for a very short ponding period a high reduction in biochemical oxygen demand may be obtained with the liquor at a high temperature. A reduction of 85 percent is indicated for a two hour period with the liquor at 90°C.

Agitation and column aeration show appreciable reduction of biochemical oxygen demand. Agitation for a two hour period at 50°C shows a maximum reduction of 50 percent. Column aeration for a two hour period shows a 30 percent reduction in oxygen demand. However, it is
quite probable that a longer period of treatment by these methods would result in a greater reduction in biochemical oxygen demand of the sulphite liquor.

VI Conclusions

The results of the experiments conducted for this report indicate that under properly controlled conditions, ponding and aeration will greatly reduce the biochemical oxygen demand of sulphite liquor. Such a reduction would accordingly diminish the demand of this waste for oxygen from the streams, and thereby eliminate the undesirable effects resulting from this demand.

Ponding and aeration is a simple treatment for sulphite liquor wastes. It is economically feasible, and when conditions demand a treatment of sulphite liquor wastes it is worthy of consideration. Although it is not an ultimate solution of the waste problem, it might be used temporarily when the stream is unable to carry the pollutional load of sulphite liquor.

The procedure of ponding and aeration is not a definite one. It might be modified in its application for the convenience and economic advantage of any particular pulp mill, and still yield sufficient reduction in biochemical oxygen demand to be effective.
VII Bibliography


APPENDIX