Evaluation of internal thermophilic biotreatment as a strategy in TMP mill closure

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CLOSED WATER CIRCUIT

ABSTRACT

Closure of the water circuit during thermomechanical pulping (TMP) was studied on the laboratory scale. Internal treatment of white waters was carried out using a thermophilic (55°C) anaerobic hybrid reactor or an aerobic moving-bed reactor. Dissolution of wood organic material in the water circuit was simulated by hot disintegration of TMP pulp in the anaerobically/aerobically treated white water. The anaerobic treatment removed all of the material dissolved during hot disintegration during the first 10 recirculations, after which there was a slight buildup in concentration. With internal aerobic treatment, organic material accumulated from the beginning of the study. It appears that the anaerobic thermophilic process, possibly in combination with other treatment such as nanofiltration, is a feasible strategy for closing the water circuit of the TMP process.

Application:

Laboratory evaluation of aerobic and anaerobic treatments to reduce COD in closed white-water circuits in TMP mills.

DURING THE PRODUCTION OF mechanical pulp, 93–97% of the wood is recovered *(1)*, which translates to a loss of 30–70 kg/ton of pulp into the water phase. The wood itself consists of cellulose (40–45%), lignin (20–30%), hemicellulose (20–30%), and extractives (2–5%) *(1)*. In thermomechanical pulping (TMP), the mechanical refining of wood into fibers is aided by heat. No chemicals are used. The pulp is then diluted with water for latency removal (hot disintegration) *(2)* before screening and thickening. TMP white water is hot, typically 50–80°C.

The effluents discharged from thermomechanical newsprint mills range from 10 to 150 m^3/air-dried (a.d.) metric ton of pulp. The current design standard for new mills is typically 10–20 m^3/a.d. metric ton *(3)*.

The organic compounds in TMP effluents consist of lignin (40%), carbohydrates (40%), and extractives (20%) *(4)*, with a chemical oxygen demand (COD) of 1000–5600 mg/L *(3)*. The ratio of COD to BOD (biochemical oxygen demand) is typically 2.2–3 *(3)*. It has been shown that a decrease in the specific effluent volume (m^3/ton of pulp) can increase the BOD/COD ratio *(5)* and, consequently, the biodegradability, possibly because of decreased dissolution of lignin and extractives *(4)*.

Closure of white-water systems in integrated mechanical pulp and paper mills may have several important benefits:

- Savings of fiber, filler, and fines
- Lower fresh-water consumption
- Reduced costs for effluent treatment.

On the other hand, closure can also give rise to a number of problems *(5–7)*:

- Increased temperature and concentrations of dissolved colloidal and suspended white-water contaminants
- Diminished product quality because of higher deposits and biological growth.

Current technology makes system closure possible *(7, 8)*, and some zero-effluent mills are already in operation. The internal treatment methods that have been applied in primary-fiber zero-effluent mills include a combination of evaporation and thermal treatment of concentrates *(9)*, wet-end chemistry *(10)*, and freeze crystallization *(8)*. For secondary-fiber mills, the internal treatments include trickling filter *(5)* and activated sludge combined with chemical/physical precipitation *(11)*.

Additional treatment technologies are being investigated in the laboratory, including thermophilic and mesophilic anaerobic treatment *(12, 13)*—possibly in combination with membrane filtration *(8, 14)*—and membrane filtration alone *(15)*.

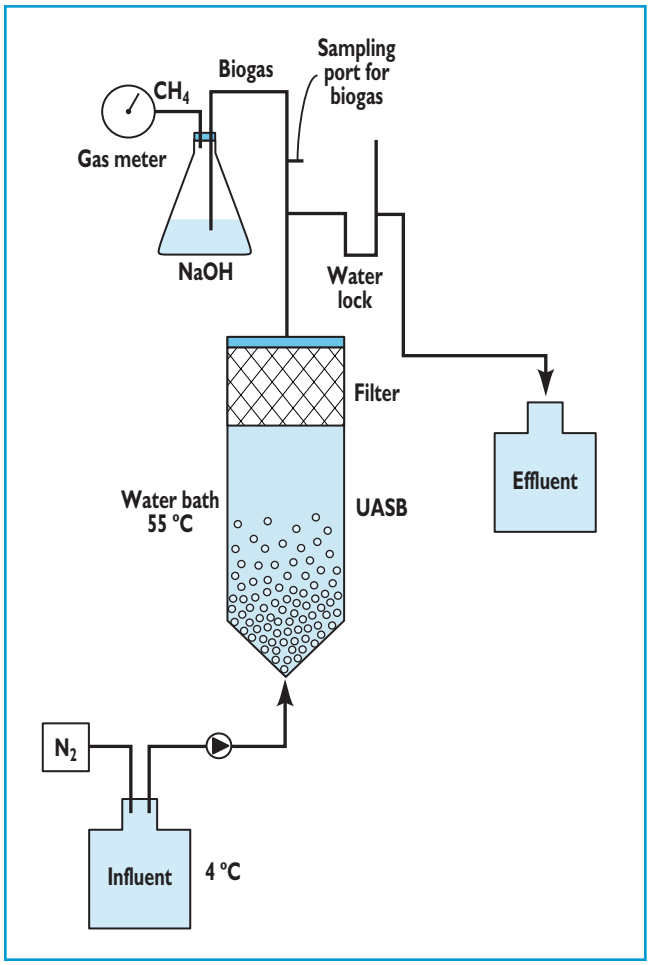
Thermophilic bacteria, with an optimum temperature of 55°C or higher, are found in both aerobic and anaerobic systems *(16)*. Treatment at such temperatures could obviate the need to cool the process water, enabling the treated water to be recycled in the mill without heating. Thermophilic treatment of TMP white water and recycled water at 55°C was found to be advantageous under anaerobic conditions *(12, 17)*. Aerobic post-treatment of anaerobically pretreated TMP white water at 55°C has been successfully applied in the laboratory *(17)*.

Biofilm processes, particularly those using moving carriers, have recently gained wide interest as a method of treating pulp and paper mill wastewaters because of the anticipated high loading potentials *(18, 19)*. For example, the aerobic mov-

Parameter	Mean	Standard deviation	Range	Number of samples
Temperature at mill, °C	…	…	70–80	…
pH	4.7	0.2	4.5–4.9	5
Total solids (TS), %	0.22	0.02	0.21–0.25	5
Volatile solids (VS), %	0.17	0.01	0.16–0.18	5
Suspended solids (SS), mg/L	91	58	28–158	5
Volatile suspended solids (VSS), mg/L	79	55	23–144	5
Chemical oxygen demand (COD)				
Total COD, mg O_2/L	2440	261	2100–2800	5
Soluble COD, mg O_2/L	2140	167	2000–2400	5
Total organic carbon (TOC), mg/L	754	107	670–890	5
Seven-day biochemical oxygen demand (BOD_7)				
Total BOD_7, mg O_2/L	1090	152	950–1300	5
Soluble BOD_7, mg O_2/L	984	143	800–1200	5
Total nitrogen (N_{tot}), mg/L	9.7	1.1	8.4–11	4
Total phosphorus (P_{tot}), mg/L	1.6	0.2	1.3–1.8	5
Carbohydrate COD, mg O_2/L	1240	114	1100–1400	5
Ligninlike material COD, mg O_2/L	628	83	510–730	5

* As measured in fresh white water from the mill

I. Characteristics of TMP white water *



1. Anaerobic hybrid reactor

ing-bed biofilm process *(20)* is being used in full-scale treatment of wastewater from an integrated newsprint mill under mesophilic conditions *(21)*.

This study evaluates the feasibility of inserting a thermophilic biological treatment step to close the water circuit of the TMP process. The study focuses on the accumulation of organic materials in the recirculated water and its effect on the process performance of the hot disintegration and the internal treatments.

MATERIALS AND METHODS

TMP pulp and white water

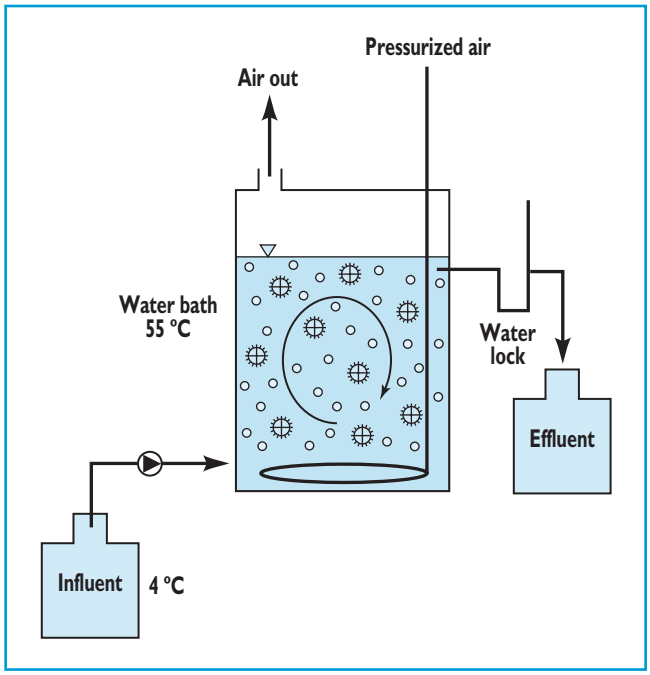
The TMP pulp and the TMP white water were obtained from a pulp and paper mill using spruce as the raw material. The TMP pulp was taken directly from the discharge of the refiner, before dilution. Two batches of pulp were obtained for the study. The first batch was collected in the middle of March (total solids (TS) of 44.8%), and the second batch was collected at the end of May (TS of 50.3%). Shortly after sampling, batches corresponding to 100 g TS were weighed into polyethylene bags and stored at –24°C until used. New white water was obtained every third week. The white water was refrigerated at 4°C until used for feed preparation.

The characteristics of the TMP white water used to cultivate the biomass employed in the present study are listed in **Table I**. The white water was supplemented with nutrients, buffer, and pH control as described elsewhere *(22, 23)*.

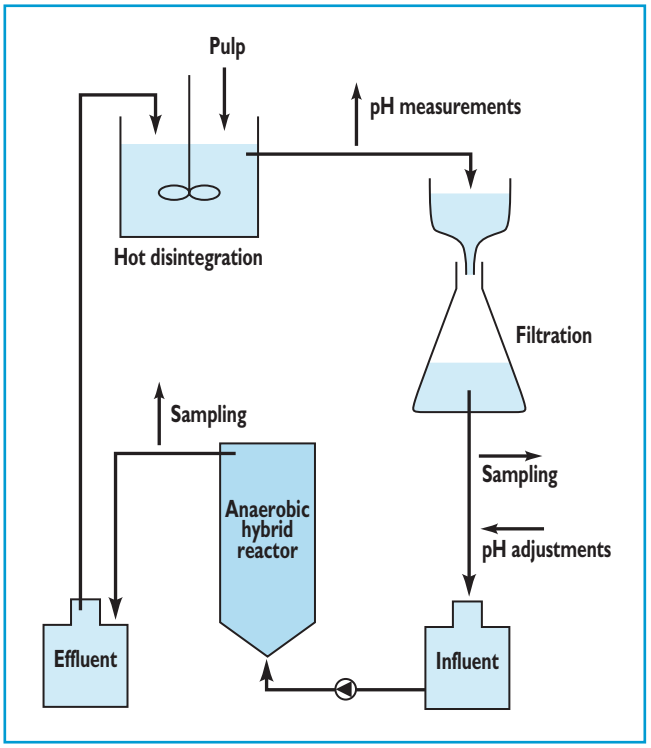
Anaerobic and aerobic reactors

A cylindrical anaerobic reactor with a total volume of 1300 mL was used in the study. The total reactor height was 285 mm, and the diameter was 77 mm. The lower 900 mL of the reactor was used as an upflow anaerobic sludge blanket (UASB) reactor, while the upper 400 mL, separated by a grid, was filled to 60% with a polyethylene biofilm carrier *(20)* that served as an anaerobic floating filter, as seen in **Fig. 1**. Gas production was measured with a wet-test gas meter (Ritter Kunststoffwerk) after the gas had been passed through a 5*M* NaOH solution to remove CO_2.

For the aerobic treatment, a moving-bed biofilm reactor *(20)* with a total liquid volume of 3550 mL was used. The Kaldnes biofilm carriers *(20)* occupied 58% of the reactor's empty volume. The reactor was agitated by aeration, as seen in **Fig. 2**. The aerobic reactor effluent was



2. Aerobic moving-bed biofilm reactor



3. Experimental setup for the closed-water-circuit experiments with anaerobic internal treatment

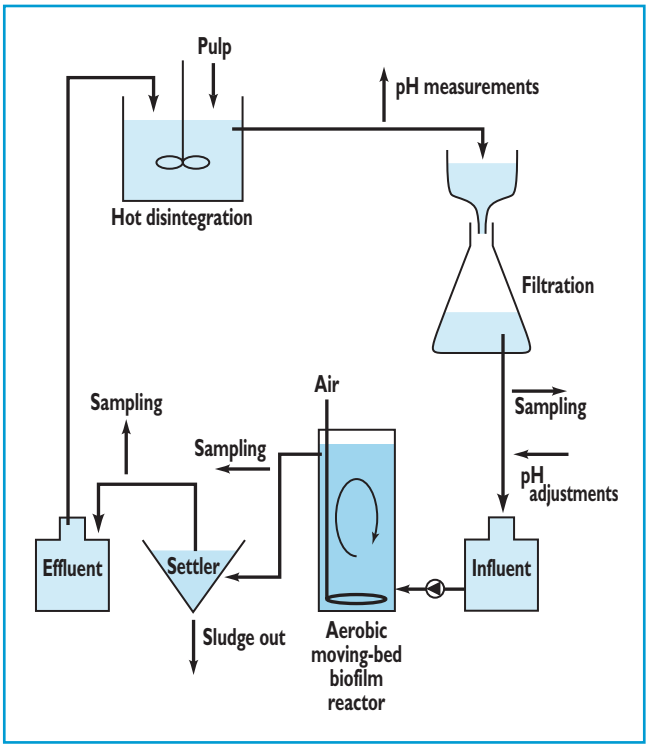
settled in a 1500-mL settler after leaving the biofilm reactor. There was no sludge recycling.

The anaerobic and aerobic reactors and the settler were kept in a temperature-controlled water bath at 55°C. The feed was heated in the inlet tubes in the water bath before entering the reactors.

Before beginning the closed-water-circuit experiments, the anaerobic reactor was operated on TMP white water for four months at loading rates up to 15 kg soluble COD/m^3·day and 60–65% removal of soluble COD *(22)*, while the aerobic process treated the same white water at loading rates up to 3.8 kg soluble COD/m^3·day and soluble COD removals of 60–65% for 3.5 months *(23)*. The reactors contained microbial populations enriched during those runs. The initial inocula of the reactors are given elsewhere *(22, 23)*.

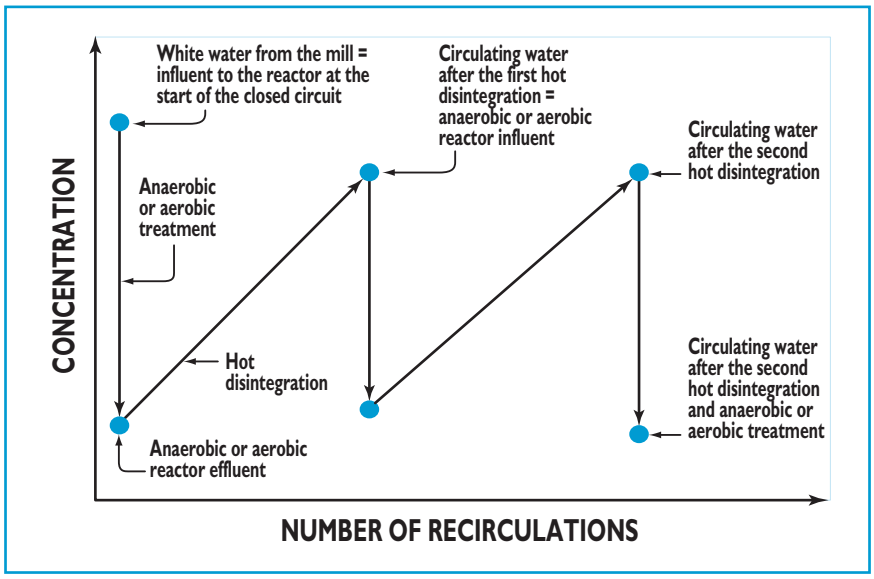
Closed water circuits

The principle of the closed water circuit with internal biological treatment is shown in **Figs. 3 and 4** for the anaerobic and aerobic reactors, respectively. The hot disintegration experiments *(4)* were carried out according to previous description and modifications *(12)*. The fresh pulp was diluted to 2% TS with the anaerobic or aerobic effluent, and the 5-L suspension was agitated at 60°C for 90 min. Agitation was provided by a large bladed propeller operated at 250 rpm. The hot suspension was then suction filtered using a glass funnel with a fritted glass filter (Schott, porosity 2). The TS of the pulp mat after suction filtration was approximately 25%. After adjusting the pH to 7.0, the filtrates were given as feed for the reactors.

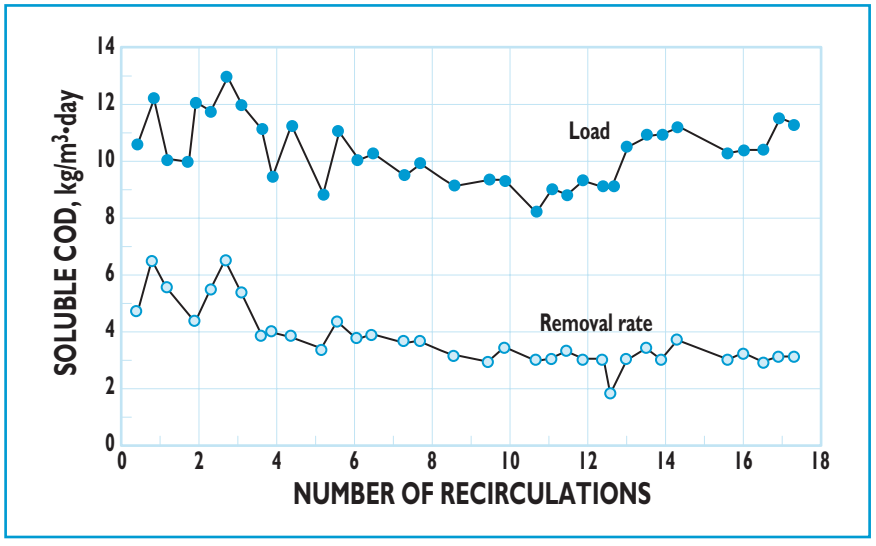


4. Experimental setup for the closed-water-circuit experiments with aerobic internal treatment

The closed water circuits were started with hot disintegration using effluents from anaerobic or aerobic treatment of TMP white water. After the first hot disinte-



5. Guide to interpreting results in Figs. 7 and 9



6. Organic loads and removal rates for the thermophilic anaerobic reactor during the closed-water-circuit experiment

gration, the filtered water (as previously described) was added to the anaerobic or aerobic influent container. The influent containers were kept at 4°C. The anaerobic feed was flushed with N_2 and stored under N_2 to ensure anaerobic conditions. Effluents from the anaerobic and aerobic reactors overflowed into effluent containers. Subsequently, the total volumes of the effluents were used for hot disintegration by adding the water to the influent container, which contained some water from previous hot disintegration. The first recirculation was considered complete when the amount of water passing through the reactor after the first hot disintegration equaled the total amount of water in the circuit. (The total amount of water in the closed water circuit was 22 L for the anaerobic and 20 L for the aerobic circuit.) The procedure was continued until the water had been recirculated 17.3 times in the circuit with anaerobic treatment and 5.3 times in the circuit with aerobic treatment. Samples were taken from the water immediately after hot disintegration and directly at the reactors' outlets (see Figs. 3 and 4). Since the volume of water in each hot disintegration (5 L) was different than the total volumes of water in the circuits, the numbers of data points do not match the numbers of recirculations. Hot disintegrations were made twice a day with the anaerobic effluent, and 1–2 times a day with the aerobic effluent. **Figure 5** illustrates the principle of data presentation used in subsequent figures.

The feed to the anaerobic reactor was intentionally stopped twice during the experiment. The first stop lasted for 2.5 days and the second stop for 1.5 days. The second shutdown occurred almost simultaneously with the change to the second batch of pulp for the final portion of the experiment. Nutrients were added to the circulating water in the anaerobic circuit at startup and again after four recirculations of the water to compensate for assumed nutrient limitation. Pulp from the second batch was used exclusively in all hot disintegrations during the closed-circuit experiment with aerobic treatment. Nutrients were added to the aerobic influent at startup of the closed-water-circuit experiment and again after the second recirculation.

Analyses and calculations

The pH measurements (Orion pH electrode) were conducted immediately after sampling to avoid changes caused by loss of CO_2 from the liquid. Filtered (GF/A) and unfiltered COD (soluble COD and total COD, respectively) and seven-day biochemical oxygen demand (soluble BOD_7 and total BOD_7), total phosphorus (P_{tot}), total nitrogen (N_{tot}), total solids (TS), volatile solids (VS), suspended solids (SS), and volatile suspended solids (VSS) were determined according to APHA standard methods *(24)*. Volatile acids (VA) and alkalinity (ALK) were measured by direct titration *(25)*. Total organic carbon (TOC) was analyzed with a

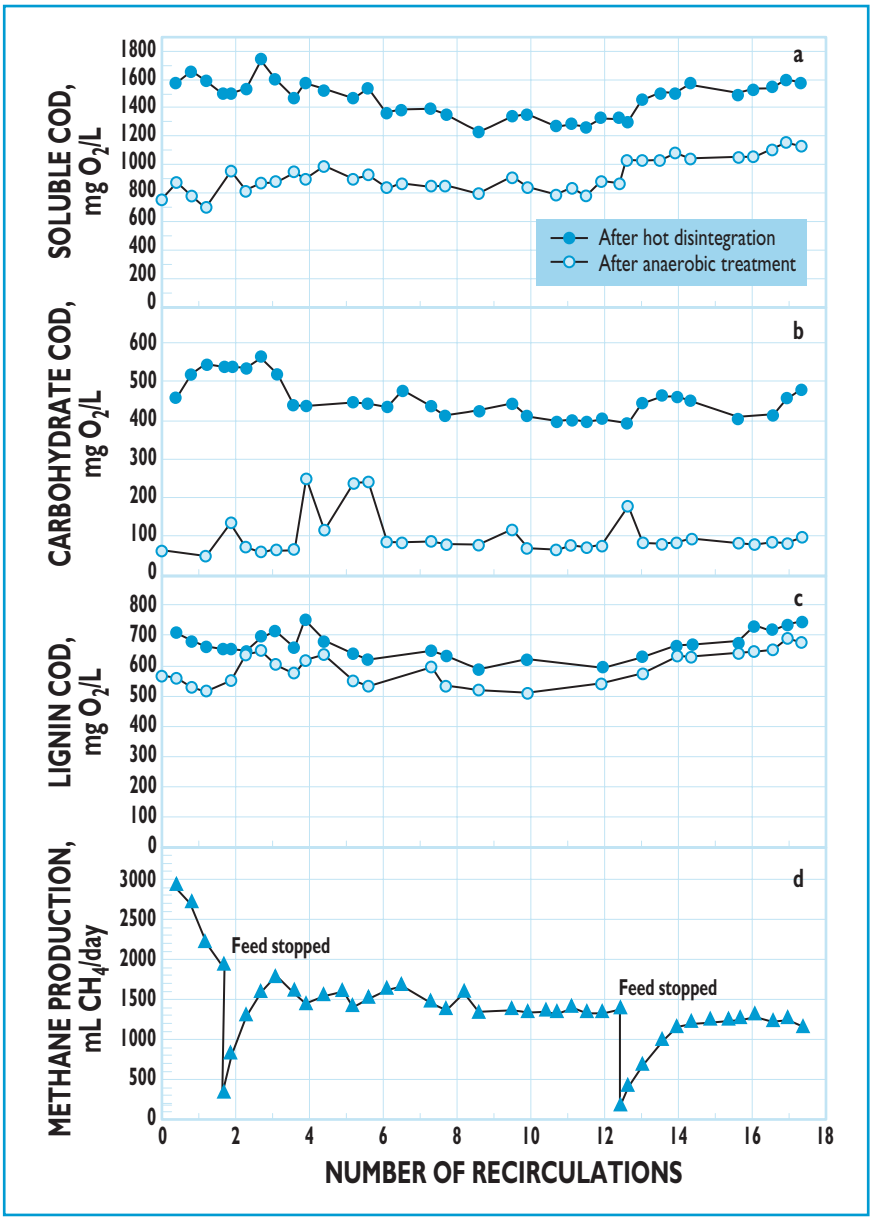
Shimadzu TOC-5000, as described previously *(12)*. Methane was analyzed by gas chromatography *(17)*. Carbohydrates were determined according to Dubois *et al. (26)* by measuring against a linear standard made with glucose. Other authors *(27)* have used a mixture of monosaccharides found in TMP water as a standard for carbohydrates. Ultraviolet absorption at 280 nm (UV_{280}) was used to determine the lignin content *(17)*. (Note that other compounds, especially aromatic extractives, also absorb light at 280 nm *(28)*). The COD of ligninlike substances was estimated by using Beer's law with an absorptivity coefficient of 22.3 L/g·cm *(28)* and a COD factor of 1.9 mg O_2/mg lignin. Total sulfide was analyzed by the spectrophotometric method described by Trüper and Schlegel *(29)*.

Soluble COD was used to express the organic material in the water and the dissolution of organic material from the pulp. The soluble COD accounted for more than 90% of the total COD in random samples.

RESULTS AND DISCUSSION

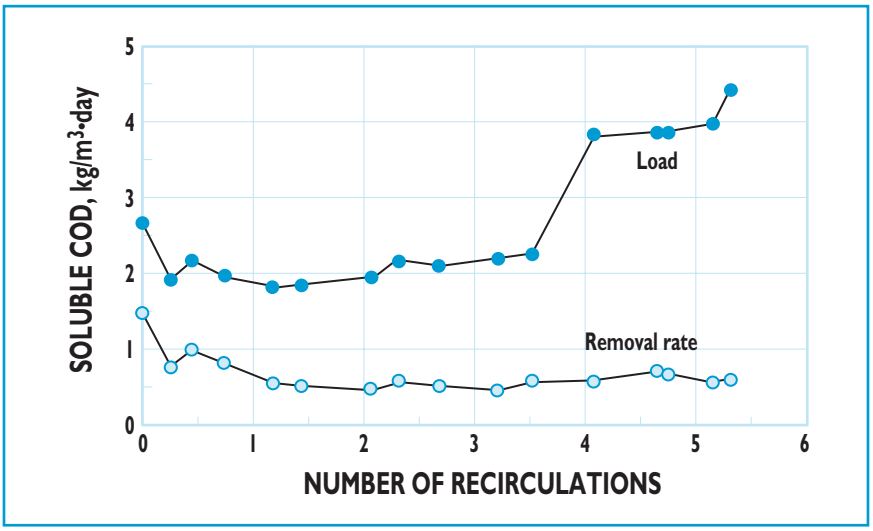
Anaerobic experiment

The anaerobic thermophilic reactor was run at a hydraulic retention time (HRT) of 3.5 hours. **Figure 6** shows that loads to the anaerobic reactor were in the range of 8.5–12.8 kg soluble COD/m^3·day. The estimated biologically degradable COD loading rates (discussed later) were in the range of 3.5–7.8 kg biodegradable soluble COD/m^3·day (Fig. 10). These loading rates were 3–4 times higher than in our previous experiments *(12)*. The COD removal was quite constant, removing all of the dissolved soluble COD, and no excessive sludge washout occurred. Thus there were no signs of loading capacity limitations. A previous study reported loading rates up to 20–80 kg COD/m^3·day during treatment of TMP white water in a laboratory-scale 55°C anaerobic process *(17)*.



7. Results from closed-water-circuit experiment with internal anaerobic treatment; a: soluble COD, b: carbohydrate COD, c: ligninlike material COD, and d: methane production

The integrated anaerobic reactor also showed stable performance during the feed stops. When the reactor was stopped for the first time (Recirculation 2), it took about one recirculation to regain normal operation, as seen in **Fig. 7**. After the second reactor stop (Recirculation 12), the levels of soluble COD in the anaerobic effluent showed a sharp increase followed by a similar increase in the water after hot disintegration (Fig. 7a). This could have been caused by the switch to a different pulp batch for use in hot disintegration after Recirculation 12. During Recirculation 4, the level of carbohydrates in the anaerobic effluent increased suddenly (Fig. 7b), while no changes were observed in soluble COD and methane performance. The previous concentration level and normal performance for carbohydrates were restored after adding trace and macronutrients to the water.



8. Organic loads and removal rates for the thermophilic aerobic reactor during the closed-water-circuit experiment

	Startup	End
Suspended, mg VSS/L	200	34
Attached, mg VSS/L	1200	2100

II. Biomass in the aerobic reactor at startup and end of the closed-water-circuit experiment

Methane production was 260–340 mL CH_4 per g soluble COD removed, and the methane content of the biogas was 55–65%. These levels were similar to those observed in the anaerobic reactor treating TMP white water before starting this closed-water-circuit experiment *(22)*. The methane production followed the feed patterns, with the feed stops resulting in temporarily lower methane productions, as seen in Fig. 7d.

Water characteristics in closed water circuits with internal anaerobic treatment

The process water characteristics after hot disintegration (before anaerobic treatment) and after anaerobic treatment are shown in Figs. 7a–7c. The initial soluble COD of the water (effluent from anaerobic treatment of TMP white water) before the first hot disintegration was similar to that used in our previous experiment investigating internal anaerobic treatment in a closed water circuit *(12)*. In the present study, the soluble COD after the first recirculation was the same as it was at the beginning of the experiment, while in the previous study, the soluble COD decreased during the first recirculation. This indicates that the amount of nonbiodegradable or slowly biodegradable material in the water was higher in the present study. In both studies, the levels of soluble COD in the anaerobic effluents and after hot disintegration were stable for 10 recirculations or more. The same pattern was observed for the carbohydrates and ligninlike material. This implies that the anaerobic treatment removed all of the organic material that was dissolved during the hot disintegration. Beginning at Recirculation 12 and onwards, a slight increase in the soluble COD and lignin COD was observed.

The lowest soluble COD value after anaerobic treatment in the beginning of the study was 700 mg/L, which could be considered the nonbiodegradable soluble COD. Some nonbiodegradable or slowly biodegradable soluble COD dissolved in the water during the experiment. Consequently, the nonbiodegradable soluble COD was significantly higher, around 1100 mg/L, at the end of the experiment.

The total sulfides were around 35 mg/L in the water before the first hot disintegration. The concentration in the water after hot disintegration and anaerobic treatment decreased to < 1 mg/L after 2 recirculations and remained at that level for the rest of the experiment. The pH was 6.5–7.3 both after anaerobic treatment and hot disintegration. The VA/ALK ratio was less than 0.3 from the beginning of the study, implying stable operation in the anaerobic system. The water took on a dark brown color during the first hot disintegration, which remained throughout the experiment.

Aerobic experiment

The aerobic experiment was run at an HRT of 18 hours through Recirculation 4, after which it was decreased to 11 hours for the rest of the experiment. The respective loading rates were 2 and 4 kg soluble COD/m^3·day, as seen in **Fig. 8**, and the biodegradable COD loading rates were 0.4–1.0 kg soluble COD/m^3·day. It was assumed that the nonbiodegradable soluble COD was 840 mg/L at startup, increasing gradually to 1600 mg/L after 5.3 recirculations. The aerobic process removed 50–100% of the soluble COD dissolved during hot disintegration.

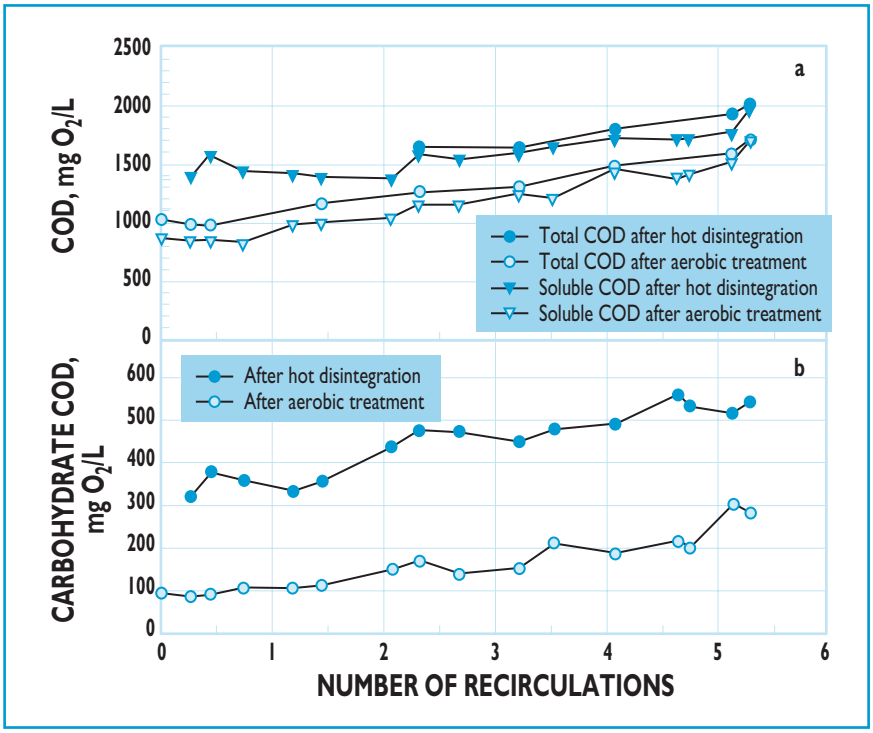
In the beginning of the run, the aerobic reactor contained 5–6 g VSS of biomass, out of which about 70% was found to be attached growth *(23)*. During the run, the suspended biomass decreased, while the attached biomass increased, resulting in an overall increase in biomass in the reactor, as seen in **Table II**. The amount of biomass in the reactor was lower than found in a mesophilic moving-bed biofilm reactor treating NSSC (neutral sulfite semichemical) effluent (7 g TS/L *(30)*). Finnish mesophilic activated-sludge plants treating pulp and paper mill wastewater have biomass concentrations of 2.5–10 g MLVSS/L (calculated from Saunamäki *(31)*).

The increase in the sludge load from 1.2 to 2.0 kg soluble COD/kg VSS·day (the biodegradable soluble COD sludge load increased from 0.3 to 0.4 kg soluble COD/kg VSS·day)

did not affect the removal rates. Sludge loads in pulp and paper wastewater mesophilic activated-sludge treatment plants are 0.15–0.65 kg BOD/kg MLSS·day *(31)*, which equals 0.4–2.4 kg COD/kg VSS·day (calculated with a COD/BOD ratio of 2.2–3.0 and a SS/VSS ratio of 0.8). Loading rates to the aerobic reactor were thus in the normal range.

Water characteristics in closed water circuits with internal aerobic treatment

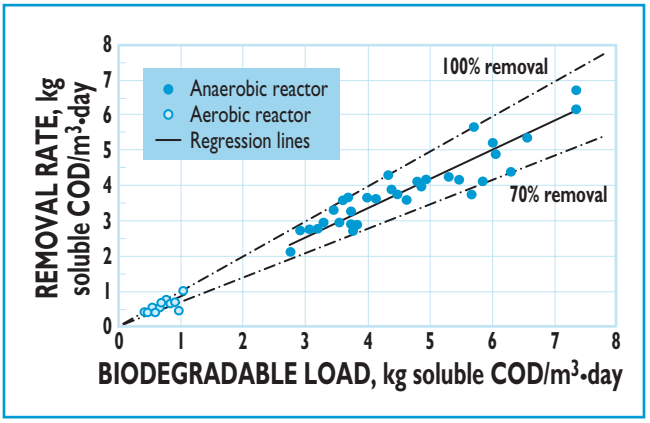
The total COD, soluble COD, and carbohydrates concentrations in the water increased slowly, with a steady slope, from the beginning of the experiment, as seen in **Fig. 9**. The UV_{280} analysis for lignin content showed increasing values even in the aerobic treatment (data not shown). The increase in UV_{280} during aerobic treatment could possibly be explained by the formation of colloidal material (during thermophilic aerobic treatment) that was not removed during sample preparation. Other authors *(17, 32)* report no problems using the same method for anaerobically pretreated aerobic effluents. Aerobic bacteria have been reported to reduce lignin in TMP effluent by 45% *(27)*. The circulating water had a light brown color.



9. Results from closed-water-circuit experiment with internal aerobic thermophilic treatment; a: total and soluble COD and b: carbohydrate COD

The second pulp batch that was used in the final portion of the experiments in the anaerobic reactor (after the second shutdown) was used exclusively in the experiments in the aerobic reactor. The nature of this pulp may have influenced the concentration levels in the water. When operating the aerobic reactor on white water obtained from the mill at the same time as the second batch of pulp—prior to the closed-water-circuit experiment—lignin removals of 0–10% were obtained. Prior to that, the removal of ligninlike material had been 5–20% *(23)*. The increased contribution from carbohydrates to the soluble COD dissolved or removed also implies that there were changes in the composition of the pulp from the first to the second batch.

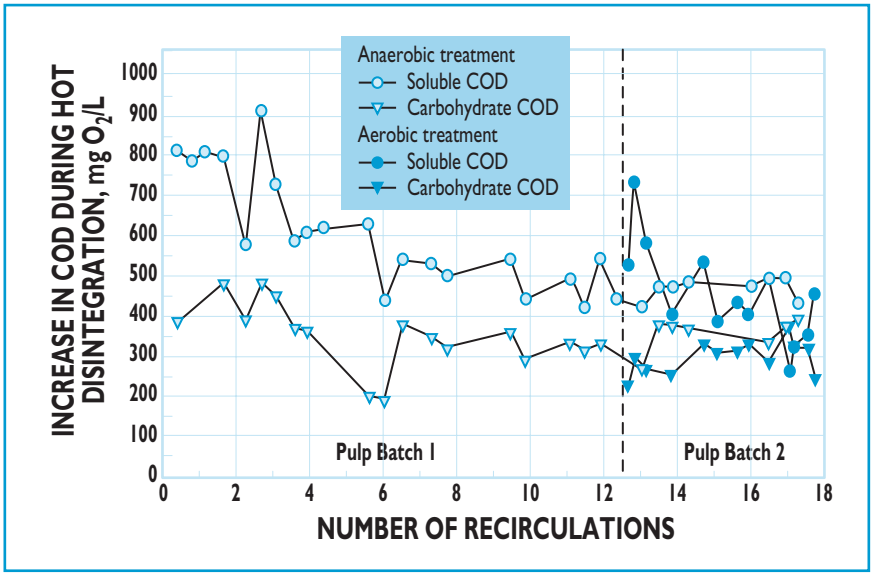
The amounts of nutrients added to the circulating water (400 mg N and 80 mg P) gave a soluble $COD_{removed}$:N_{added}:P_{added} ratio of 100:1.3:0.3. Activated-sludge plants treating pulp and paper industry wastewater generally operate with a COD : N : P ratio of 100 : 5 : 1 *(3)*. There might have been a nitrogen or phosphorus deficiency in the reactor, thus reducing the removal of organic material. The increase in effluent carbohydrates during the experiment also implies that the aerobic reactor performance was not optimal.



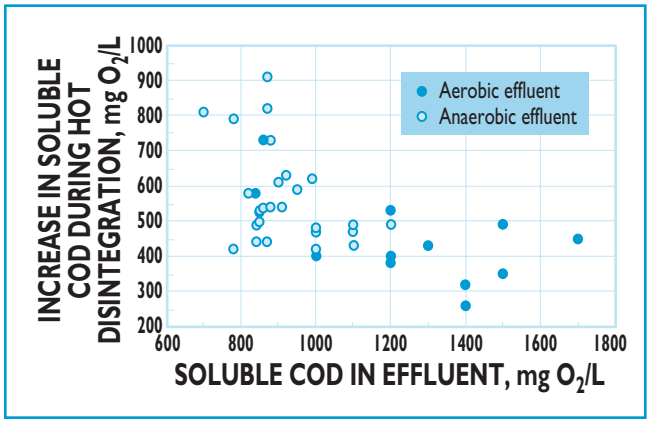
10. COD removal rates vs. biodegradable loads to the anaerobic and aerobic reactors

Internal anaerobic vs. aerobic treatment

In **Fig. 10**, the removal rates are plotted against the biodegradable soluble COD loading rates. The linear regression lines indicated soluble COD removal efficiencies of 84% in the anaerobic and 86% in the aerobic reactor. The data show a linear increase in removal rate with increasing loading rate. This indicates that the maximum capacities of the processes were not reached during the study.



11. Increases in soluble COD and carbohydrate COD during hot disintegration for anaerobic treatment (Pulps 1 and 2) and aerobic treatment (Pulp 2 only). (Note that the five recirculations for the aerobic treatment are overlaid on the right-hand side of the graph to correspond with the introduction of Pulp 2 in the anaerobic treatment.)



12. Increases in soluble COD during hot disintegration as a function of soluble COD concentration in the water for anaerobic and aerobic treatments

Figure 11 shows the increases in soluble COD and carbohydrates following hot disintegration of the anaerobic and aerobic effluents throughout the experiments. The recirculation numbers on the *x*-axis correspond to the runs in the anaerobic reactor. The five recirculations for the aerobic treatment are overlaid on the right-hand side of the graph to correspond with the introduction of Pulp 2 in the anaerobic and aerobic treatments. The increases observed during hot disintegration of Pulp 2 for the anaerobic and aerobic effluents indicate that there was a difference between Pulps 1 and 2, with Pulp 2 producing higher levels of dissolved organic material during hot disintegration. Because the ligninlike portion of the soluble COD dissolved during hot disintegration did not change during the experiment, the increase in soluble COD in the water must have come from something other than ligninlike material. Studies on seasonal variation in extractives show that their composition remains nearly constant throughout the year, while simple carbohydrates are much lower during spring and summer *(33)*. Heartwood tannins are often higher during summer and tend to be higher in younger trees *(34)*. Analyses of TMP pulp showed significant differences in extractives composition between November and April *(35)*. Wood storage also affects the composition of the lipophilic extractives *(1)*. It is possible that increased levels of wood tannins or extractives in the second pulp batch contributed to a higher level of nonbiodegradable soluble COD in the water.

Laboratory tests have shown that the dissolution of organic material from the wood decreases as the water consumption in the mill goes down *(4)* and when the filtrate concentration increases *(4, 12, 35)*. This is confirmed in **Fig. 12**, where the increase in soluble COD during hot disintegration is shown to be highly dependent on the concentration of soluble COD in the effluent before hot disintegration. The COD treatment efficiencies for ligninlike material and the increases in lignin COD during hot disintegration were higher in previous closed-water-circuit experiments, where the COD concentrations in the suspension were lower *(12)*. Treatment efficiencies in the anaerobic reactor treating TMP white water prior to the closed-water-circuit experiments *(22)* were 15–16% for ligninlike material and 95% for the carbohydrates. Buildup of nonbiodegradable or slowly biodegradable material in the circulating water was probably the reason why the treatment efficiencies in the closed-water-circuit experiment were lower than they were prior to closure of the system. Apparently, the COD concentrations in the white water and the pulp composition both play an important role in determining the amounts of COD that will dissolve during hot disintegration (Figs. 11 and 12).

EFFECTS ON PRODUCT QUALITY

The material in the pulp that is not dissolved during the hot disintegration will ultimately be used for paper production. When the amount of organic materials dissolved from the pulp into the water decreases because of the high concentrations already present in the water, more lignin and carbohydrates will remain in the pro-

duced pulp. Thus removal of the dissolved compounds by internal treatment may lead to enhanced dissolution from the pulp.

The color of the anaerobically treated water would greatly affect its reuse in the mill because it imparts color to the fibers during the hot disintegration *(12)*. The presence of ligneous compounds is responsible for the high color levels in many pulp and paper industry effluents *(36)*. Increased color levels have been observed upon aeration of anaerobically treated paper mill wastewater *(17, 37)*. In the present study, the anaerobic effluent showed an increase in color when exposed to oxygen during suction filtration after hot disintegration. This was probably due to the oxidation of phenolic compounds formed in the anaerobic treatment when the water was exposed to oxygen *(36)*. Anaerobic treatment of the water from hot disintegration did not remove the color. Aerobic treatment alone has not been found to increase the color of the white water *(37)*.

It seems that neither anaerobic nor aerobic internal treatment alone is safe enough to be integrated in the TMP and paper mill closed water circuits, although integration with membranes could be a feasible system. Nanofiltration has been found to be capable of reducing UV_{280} and UV_{400} in anaerobically treated TMP white water by 98–99% *(14)*.

CONCLUSIONS

The thermophilic anaerobic reactor removed the organic material (soluble COD, carbohydrates, ligninlike material) dissolved during hot disintegration for more than 10 recirculations of the water, after which there was a slight buildup in concentration. On the other hand, thermophilic aerobic treatment was not capable of removing all of the soluble COD and carbohydrates dissolved during hot disintegration. This may have been caused by nutrient deficiency. However, the accumulation of organic material in the water probably came from the dissolution of nonbiodegradable material from the pulp during hot disintegration. **TJ**

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