BIOLOGICAL TREATMENT OF BCTMP WASTE WATERS

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CTMP PROCESS

Bleached Chemi-Thermo Mechanical Pulping (BCTMP) is a new efficient process for pulp production. When compared with conventional kraft mills, BCTMP mills require a lower initial capital investment, give a higher pulp yield, require fewer personnel to operate and the cost per ton of pulp is lower. The older refiner mechanical pulp (RMP) and thermo mechanical pulp (TMP) mills have either converted to utilize the BCTMP process, integrated into paper mills or have been shut down.

BCTMP AND KRAFT MILL COMPARISON

The following table by Sherman **(Ref.1)** shows a comparison for a 750 average dry tons per day Aspen BCTMP mill and a Aspen bleached kraft mill in Western Canada.

ITEM	UNIT	BCTMP	KRAFT
Yield	%	90	50
Personnel	Number	100	300
Energy	ADT/Kwh	3000	750
Water	M3/ton	20-25	50-60
Effluent-BOD_5	Kg/ton	60-80	20-30
Emission - air	-	Odorless	Smell
Operating cost	$/ADT	300	360
Capital cost	US$ Million	200-220	550-600

WASTE WATER CHARACTERISTICS

The effluent produced in a BCTMP mill is mainly from chip washings, press filtrate and white water purge.

The following is a comparison of raw effluent waste water produced from a CTMP and a Thermo Mechanical Pulp (TMP) mill **(Ref. 2).**

	CTMP WASTE	TMP WASTE
FLOW, M3/ADT	22	16
BOD5, MG/L	3100	1600
BOD5 KG/ADT	82	26
SS, mg/l	221	209
RESIN ACIDS, MG/L	42	17

RESIN ACID COMPOSITITION

Resin acids are known to cause toxicity in the effluent waste water. The following table shows a comparison of the resin acids present in CTMP and TMP process waste waters.

	CTMP (mg/l)	TMP (mg/l)
Abietic	8.86	4.21
Dehydroabietic	15.37	5.33
Isopimaric	6.94	2.41
Pimaric	4.35	2.23
Sandopimaric	1.83	0.65
Leuopimaric	4.37	2.24
Total resin acids	41.72	17.07

PERCENTAGE BASIS	CTMP	TMP
Flow M3/ADT	73 %	100 %
BOD kG/ADT	315 %	100 %
BOD mg/l	193 %	100 %
Resin acids KG/ADT	182 %	100 %
Resin acids mg/l	250 %	100 %

The concentration of BOD produced from a CTMP mill is almost 200 % higher and resin acids 250 % higher than in a TMP mill. Resin acids are known to cause toxicity in the waste water. It is apparent from the above data that CTMP waste waters are more complex and difficult to treat than TMP waste waters.

NEW BCTMP MILLS

Fibreco Export constructed a new BCTMP mill in 1988 in Taylor, B.C. This mill is designed to produce 600 average dry tons /day (ADT/day) (180,000 ADT/yr) pulp and was started up during the summer of 1988. This mill is designed by H.A. Simons Ltd in Vancouver, B.C.

Millar Western Pulp Limited constructed a new BCTMP mill in 1988 in White Court, Alberta. This mill is designed to produce 700 ADT/day (210,000 ADT/yr) pulp and was started up during the summer of 1988. This mill is designed by Nystrom, Lee, Kobayashi Inc. in Vancouver, B.C. On a production and design capacity basis, Millar Western Pulp Limited is the largest operating BCTMP mill in the world.

PROCESSES CONSIDERED

Aerobic stabilization basin (ASB), air activated sludge with a secondary clarifier and pure oxygen systems were evaluated for the waste treatment process at the above two new BCTMP mills in Canada. The ASB system was selected because of the following reasons:

Pure oxygen system at Fibreco mill was not selected because " Pure oxygen system for the same waste loading with short retention times plus secondary clarifiers and waste activated sludge dewatering, requires additional expenditure that exceeds the ASB by 2.5 times". **(Ref. 3).**
Activated sludge system was ruled out because the capital cost was higher than ASB.

A aerobic stabilization basin (ASB) system was selected for the following reasons:

* ASB system would meet the effluent permit guidelines.
* No sludge handling facilities would be required.
* System was cost effective.
* ASB system would be able to buffer slugs of shock loads without appreciable variations in effluent quality.

AERATION SYSTEMS CONSIDERED

The following aeration systems were considered at Fibreco and Millar Western Pulp mills.

Jet Aerators
Surface Aerators
Static aerators
Fine bubble dome diffusers.

Surface aerators were ruled out because they are not suitable for cold climates where freezing can occur. In addition, the oxygen transfer efficiency of surface aerators is low. Higher operating costs would be incurred with surface aerators.

Fine bubble diffusers need cleaning every five years. The ASB lagoons at these mills are not expected to be drained for 20 years.

Static aerators were less efficient than jet aerators. The expected oxygen uptake rate in certain parts of the ASB basin was as high as 40 mg/l/hr and sufficient static aerators could not be added in the lagoon volume to provide the required oxygen uptake rate. Mixing on the slopes would not be very good.

A jet aeration system which has proven its performance in over 50 pulp and paper mills was selected for the following reasons:

1. Energy savings over other aeration devices.
2. Jet aeration systems achieve high toxicity removal efficiency and good pH control in the lagoon.
3. The system was cost effective.
4. Low maintenance is required by jet aeration systems.
5. Independent control over oxygen transfer and mixing. Jet aeration systems can vary oxygen transfer at various points in the aerobic reactor. The system is suitable for nitrification and denitrification.
6. Jet aerators are efficient mixing and mass transfer devices.
7. Thermal gradients are minimized in the lagoon.
8. Aerators are submerged and the system does not freeze in cold climates.

PRINCIPLE OF OPERATION OF JET AERATION SYSTEMS

Jet aeration is a efficient gas/liquid contacting device. Jet aerators use the ejector method of contacting gases and liquids. The jet consists of a double nozzle arrangement **(Fig 1**)that has a primary inner nozzle, an intermediate high shear micro mixing chamber and an outer secondary nozzle.

Recirculation liquid (mixed liquor) from the tank is pumped through the primary converging nozzle where the motive force is converted to a high velocity, low pressure stream. The high velocity stream enters the mixing chamber where low pressure air is introduced perpendicular to the high velocity liquid stream. The two streams are efficiently contacted in the micro mixing chamber. The intimate contact between the air and liquid streams results in the formation of micron size bubbles. The fine air/liquid mixture is then discharged through the secondary nozzles with a high velocity plume. The gas liquid plume is discharged near the bottom, parallel to the floor of the tank. The horizontal travel of the plume near the bottom of the tank maintains high gas pressure conditions for efficient gas/liquid mass transfer. When the plume's initial horizontal momentum dissipates, its rise to the surface produces a vertical plume which further mixes the tank contents.

The combination of the vertical and horizontal plumes produce a unique flow pattern in the tank which results in a vertical top to bottom rolling action and a horizontal mixing action. The resultant force from these plumes creates molecular dispersion and fine eddies sending the oxygen molecules faster to the point of reaction.

The directional mix jet aerator configuration has jets mounted on one or both sides of a common header **(Fig 2).** These aerators are particularly suited for large lagoons that may require plug flow conditions.

The major components of the aeration system are the jet aerators, high volume recirculation pumps and low pressure air blowers.

FIBRECO EXPORT INC.

Fibreco located in Taylor, British Columbia constructed a new bleached chemi-thermo mechanical (BCTMP) pulp mill designed to produce 600 ADT (average dry tons/day) pulp. This plant was built during 1987 and started up in August 1988.

Fibreco produces BCTMP from a furnish of northern spruce and lodgepole pine. This furnish is supplied by sawmill chips transported by rail cars and trucks.

Limited BCTMP operating data was available and best engineering judgments were used to predict the influent, wastewater and effluent characteristics.

Fibreco uses Spruce and pine in the form of wood chips. The wood chips are screened, pre-steamed and followed by chip washing in clean water. Prior to refining, chip preparation requires chemical impregnation with additional pre-steaming. Chemicals are added prior to the atmospheric reaction. Pressurized refiners complete the primary refining before transfer to secondary refiners **(Ref:3).**

The effluent discharge is primarily from chip washing, press filtrate and white water purge.

PROCESS DESCRIPTION CTMP

The first stage of the waste water treatment process is screening and primary clarification. The raw effluent temperature can be as high as 62 ^{o}C during summer. After clarification, the waste flows into a cooling pond which also acts as a equalization basin. The cooling pond has a hydraulic detention time of one day. The cooling pond has surface coolers which are designed to achieve a temperature reduction of up to 20 ^{o}C. From the cooling pond, the waste water flows into the ASB basin. The necessary nutrients are added directly into the ASB basin.

A spill pond is available to hold unexpected emergency waste loads. This pond is provided to prevent upset conditions in the ASB basin. The spill pond is designed to gradually bleed the excess load into the ASB basin.

TOXICITY IN BCTMP MILLS

Due to the high resin acid concentrations in the raw effluent from the plant (up to 42 ppm) the effluent is toxic. Treatment efficiency is reduced with toxic effluents and increases the fish mortality.

The following factors help to reduce toxicity in the aeration lagoon:

1. Good blending of the influent waste water in the aeration reactor.
2. Elimination of short circuiting from the influent to effluent.
3. Maintain high BOD removal efficiency.
4. Control reaction temperature in the aeration lagoon.

At Fibreco, Filtered and unfiltered effluent samples collected at the outlet of the aeration lagoon are analyzed for 96 hr tlm test as follows **(Ref. 4)**

FILTERED	PERCENT SURVIVAL			
Vol/Vol Concentration	24	48	72	96 HOURS
100	100	100	100	100
75	100	100	100	100
50	100	100	100	100
25	100	100	100	100
10	100	100	100	100

UNFILTERED	PERCENT SURVIVAL			
Vol/Vol Concentration	24	48	72	96 HOURS
100	100	100	100	80
75	100	100	100	100
50	100	100	100	100
25	100	100	100	100
10	100	100	100	100

A non diluted 100 % effluent sample from the outlet of the aeration lagoon produced a non toxic effluent with zero fish kill after 96 hours in the undiluted, filtered sample.
The ambient air temperatures when the above tests were performed were -20 to -24^{o}C and the waste water aeration temperature was 15^{o}C. At warmer aeration temperatures,

biodegradation is faster and the effluent toxicity removal is higher.

To enhance blending, the entire effluent from the primary clarifier is introduced near the first jet aeration recirculation pump. The capacity of the recirculation pump is 9 times more than the influent waste water. All the influent wastewater is therefore taken through the pump suction where it is contacted with low pressure compressed air in the jet nozzles. This influent flow is discharged with a high velocity stream through 24 berm mixing nozzles along the slopes of the lagoon and 132 aeration nozzles at the bottom of the lagoon. The velocity exiting the aeration nozzles is 33 ft/sec (10 M/sec). This micro mixing action results in instantaneous blending of the BOD and resin acids with the main lagoon volume. Concentrated influent is contacted within the jet nozzles for high BOD removal efficiencies.

This method of diluting and evenly spreading the influent throughout the lagoon volume can handle periodic plant upsets and shock load conditions.

BERM MIXING

Operating data from previous operating plants have shown that good berm mixing will benefit the treatment process and will minimize short circuiting in the lagoon.

In deep aeration sloped bottom lagoons, a significant volume of the lagoon is on the berms. It is extremely important to assure that sufficient blending will occur on the berms such that the entire volume of the lagoon can be utilized for aeration and toxicity removal.

At Fibreco, 64 percent of the total volume of the lagoon is on the berms.

The berm mixers in this case consume 20 % of the pump recirculation power. Berm mixers contribute a little in achieving improved oxygen transfer efficiency but significantly help in the overall BOD and toxicity removal efficiencies.

Twenty percent of the total pump recirculation energy is used exclusively for mixing the berms. The remaining 80 % is used for aeration and mixing the remaining portions of the lagoon.

TEMPERATURE EFFECT

Aerobic stabilization basins are sensitive to aeration temperatures in the lagoon.

The ideal aeration temperature is 20 to 35^{O}C. The temperature from a BCTMP mill is around 50 degrees C. In the summer months when the ambient air temperature is high, the waste water is allowed to cool in a cooling pond and some cooling also occurs in the primary clarifier.

The waste water entering the aeration lagoon can be as high as 40 degrees C. Under these conditions it is desirable to achieve cooling in the aeration pond. The cooling pond has two floating surface spray coolers which cause the waste water to splash into the atmosphere and cool by five to 10 ^{O}C.

During winter, the ambient air temperature falls to as low as -40 ^{O}C. The aeration temperature in the lagoon falls to around 12 ^{O}C and it becomes necessary to bypass the cooling pond and maintain the aeration temperature around 20 ^{O}C. On very cold days, it becomes necessary to add external heat to the lagoon to maintain temperature in the lagoon to around 20 ^{O}C.

Raw effluent based for design are as follows:

Flow	22 M3/ADT (5800 gal/ ADT)
BOD5	3100 mg/l
BOD5	82 Kg/ADT (180 lb/ADT)
TSS	300 mg/l
Resin acids	42 mg/l
Fatty acids	70 mg/l

Resin acids that cause toxicity are 250 % greater in a BCTMP process than in a TMP process.

Effluent characteristics

BOD5 removal efficiency	85 % in summer
BOD5 removal efficiency	75 % in winter
Resin acids	2 mg/l

DESIGN PARAMETERS

Flow	16,000 M^3/day (4 MGD)
BOD5 applied to aeration	41,000 Kg/d (90,000 lb/day)
BOD5 removed in aeration	37,000 Kg/d (81,585 lb/day)
Lagoon dim. at water level	209 M x 117 M (686 ft x 384 ft)
Lagoon dim. at bottom	139 M x 47 M (456 ft x 154 ft)
Lagoon water depth	10 M (33 ft)
Volume of lagoon	146,000 M^3 (39 Million gallons)
Hydraulic detention time	9.1 days (7 to 10 days actual)
Dissolved oxygen	2 PPM
Alpha factor	0.8
Beta factor	0.8
Process oxygen required	47,920 Kg/hr (105,664 lb/day)
Standard oxygen required	126,600 Kg/day (279,153 lb/day)
Aeration/berm mix pumps	Four 200 HP
Berm mixing pumps	Two 50 HP
Aeration blowers	Two 900 HP
(Each blower 12,400 SCFM at 13.5 PSIG).	
Total aeration pump BHP	650
Total berm mixing BHP	170
Total blower BHP	1630
Total BHP	2450
Oxygenation capacity	2.12 Kg O2/BHP-hr (4.7 lb O2 / BHP-hr)

The power required for mixing the berms is included in the above power calculations.

EQUIPMENT DESCRIPTION

The lagoon has twelve aerators and ten mixers. Each aerator is approximately 36 M long and has 44 aeration nozzles. The ten berm mixers have an average of 18 jet mixing nozzles for mixing the slopes of the lagoon.

The aerators and mixers are arranged such that they form four separate plug flow reactors. The aerator arrangement and jet nozzle orientation directs the flow to form alternating clockwise and counter clockwise cells such that no waste can short circuit from the influent to the effluent. Each cell is approximately 117 M (384 ft) long and 36 M (118 ft) wide **(Fig 3).**

Velocity calculations were made for each cell as discussed in Jet Fluid Gas/Liquid Contacting and Mixing (**Ref 5**). The calculated velocity was 1 ft/sec (.33 M/sec). The velocity calculations indicated that the flow would go around the cell once every 15 minutes. There are four cells in the lagoon, and the entire contents of the lagoon would turn over once every hour. The lagoon has a minimum hydraulic detention time of 7 days. This indicates that the lagoon would turn over its contents a minimum of 168 times before it is discharged into the river. Mixing guidelines indicate that the tank is considered well mixed if it turns over the contents of the tank a minimum of ten times before it is discharged. Calculations indicated that there should be no problems of short circuiting and blending.

When the system was put into operation, aerial pictures of the lagoon were taken to demonstrate complete mixing (**Fig 4**). There were no indications of any stagnant zones in the lagoon. The entire lagoon including the berms were completely mixed.

The BOD_5 removal efficiency is 85 % during the summer months and 70 to 80 % during the winter months.

The system is producing non toxic, high quality BCTMP effluent.

The entire aeration and mixing system has six operating pumps and three operating air blowers. The installed jet aeration system has proven to be very reliable.

Each aerator is equipped with a back flush device which cleans the nozzles of debris that may collect in the aeration nozzles.

The jet aeration system is consistently producing a effluent which is in compliance with permit requirements.

TREATED EFFLUENT DATA

The following is actual plant operating data from February to May 1989 **(Ref: 6).**

	ACTUAL	PERMIT
BOD_5 EFFLUENT, KG/DAY	2377	4313
SS, KG/DAY	2378	4888
DISSOLVED OXYGEN, mg/l	3.2	2
Toxicity LC50, 96 hour survival	100 %	100 %
pH	7.1	6.5 to 8

MILLAR WESTERN PULP LIMITED WHITECOURT ALBERTA

Millar Western Pulp Limited manufactures pulp by the Bleached Chemi-Thermomechanical Pulping (BCTMP) process. This plant is designed to produce 210,000 air dry metric tons per year pulp. At the present time, Millar Western Pulp Ltd. is the largest BCTMP mill in the world.

WASTE WATER CHARACTERSTICS

Flow	15,000 cubic meters/day (4 MGD)
BOD5 applied to aeration	54,400 Kg/day (120,000 lb/day)
BOD5 removed in aeration lagoon	49,000 Kg/day (108,000 lb/day)
Lagoon dimensions at water level	260 M x 114 M (850 ft x 375 ft)
Lagoon dimensions at bottom	220 M x 75 M (722 ft x 246 ft)
Hydraulic detention time	8 days
Volume of lagoon	120,000 cubic meters (32 MG)

The lagoon has seven directional mix jet aerators.

The system has four 200 HP recirculation pumps and three 125 HP recirculation pumps. Total pump BHP is 892.

Two operating and one stand by low pressure blowers supply air to the aerators. Each blower is designed to deliver 15,360 SCFM at 9.2 PSIG. BHP per blower is 714.

Total pump BHP	892
Total blower BHP	1424
Total operating BHP	2316
BHP/MG	72
Total lb/day BOD5 removed	108,000
lb/day BOD5 removed/BHP	47

PROCESS DESCRIPTION

The aerators and nozzles are arranged in the ASB basin to form a completely mixed zone and a plug flow zone **(Fig 5).** The influent end of the lagoon where most of the BOD_5 *removal occurs is the* completely mixed zone. The volume of the completely mixed zone is about 65 % of the entire lagoon volume and about 75 % of BOD_5 removal occurs in this region.

The aerators are arranged to form a large circular flow pattern in the completely mixed region. Calculations indicated that the flow goes around the circle once every 30 minutes. The hydraulic detention time in the completely mixed region is 4.4 days. The waste water goes around the completely mixed reactor zone an average of 200 times before it goes into the plug flow region.

In the plug flow region, the hydraulic detention time is approximately 3.6 days. In this region, additional BOD reduction occurs. A plug flow arrangement with dividing baffles was recommended by the consultants to eliminate any potential for short circuiting of toxic resin acids.

The waste water from the primary clarifier comes into the first pump chamber. All the influent flow from this chamber is sent through 128 aeration nozzles. This action provides immediate contact of the high strength waste water with air within the jet nozzles. After the waste water is oxygenated within the nozzles, the high energy plumes shoot out into the main lagoon volume. This action provides instantaneous dilution of the waste water with the main lagoon volume.

Each 200 HP recirculation pump is designed to pump 25,000 GPM. The influent plant flow is 2780 GPM. Each 200 HP jet aeration pump in the completely mixed aeration zone is designed to recirculate 9 times greater flow than the plant flow rate in to the aeration lagoon.
Each 125 HP jet aeration pump in the plug flow zone is designed to recirculate 6 times greater flow than the plant flow rate in to the aeration lagoon. The jet aeration system has four 200 HP pumps and three 125 HP pumps. This high degree of blending is good for absorbing high shock loads through the plant.

The second half of the lagoon is the plug flow region where the flow has to pass through dividing baffles to avoid short circuiting.

Berm mixers were not installed in this lagoon because it was felt that sufficient mixing will be provided without the berm mixers.

After the lagoon was put in operation, the top edges of the berms which were 60 M (200 ft) from the aerators resulted in velocities in the range of .15 to .21 M/sec (.5 to .7 ft/sec). This is sufficient velocity to keep the entire lagoon volume mixed.

OTHER DESIGN COMCEPTS FOR BCTMP WASTES

In the next few years, governing bodies such as the EPA may not allow lined lagoons for aeration of toxic waste water.

Pilot plant tests have shown that activated sludge is a viable option for treatment of CTMP waste waters.

Activated sludge plants are more expensive to build than the ASB plants. In activated sludge plants, additional sludge disposal costs are involved.

BOD_5 concentrations as high as 4,000 PPM have been reported for CTMP waste waters. Since the BOD concentration is high in CTMP wastes, two aeration cells in series will give the required effluent standards. Due to the high toxicity of CTMP waste, anaerobic treatment has not been found to be suitable.

RECOMMENDED DESIGN PARAMATERS

Oxidation ditch flow pattern is recommended because oxidation ditches can provide conditions approaching plug flow. Study of over one hundred oxidation ditch plants showed that the oxidation ditch flow pattern consistently produced high BOD removal efficiencies with minimum operation (EPA-600/2-78-051). **(Ref. 7).**

When influent BOD_5 concentrations are less than 1500 PPM and no more than 90 % BOD removal efficiency is required, use a single stage oxidation ditch flow pattern.

When influent BOD5 concentrations are greater than 1500 PPM or higher BOD removal efficiencies are required, use two cells in series. A oxidation ditch flow pattern is recommended for both cells. **(Fig 7).**

The following design parameters are recommended for a single stage oxidation ditch when the BOD_5 concentrations are less than 1500 PPM.

F/M ration of 0.15 to 0.4 lb BOD_5 / day - lb MLVSS
2000 to 4000 PPM MLVSS
1.1 Pound process oxygen / pound BOD_5 removed
If jet aeration systems are used, design for an alpha factor of 0.8 and a beta factor of 0.95.
For low operating and capital costs, tanks with a water depth of 20 to 30 ft are recommended.

The following design parameters are recommended for two stages in series for oxidation ditches when the BOD_5 concentrations are in the range of 1500 PPM to 5000 PPM.

	STAGE 1	STAGE 2
F/M ration lb BOD_5 / day - lb MLVSS	.4-.6	.15-.4
MLVSS, PPM	3000-5000	3000-5000
Pound oxygen / pound BOD_5 removed	.8-1	1-1.2

If jet aeration systems are used, design for an alpha factor of 0.8 and a beta factor of 0.95.

For low operating and capital costs, tanks with a water depth of 20 to 30 ft are recommended.

Assuming sufficient oxygen is provided by the aeration equipment, anticipated BOD_5 removal in stage 1 is 70 % to 80 % . Anticipated BOD_5 removal in stage 2 is 85 % of BOD5 entering in stage 2.

CONCLUSION

Although the aerobic stabilization basin (ASB) process is suitable for treating CTMP waste water, during the winter months, it is difficult to control the level of BOD removal efficiency in the lagoon.

The BOD removal efficiency is sensitive to reaction temperature, hydraulic detention time and the ratio of nutrients present in the lagoon. For good treatment, a hydraulic detention time of 8 to 10 days is required. Desired temperature in the ASB basin is 20 to 35 ^{o}C.

During the summer months, cooling of waste water prior to ASB treatment is necessary for good treatment efficiency. During the winter months, cooling is not required.

For high BOD and toxicity removal efficiencies, a single cell or two cells in series activated sludge system will give better control over ASB system.

Jet aeration systems are efficient and are well suited for treating CTMP and BCTMP wastewaters.

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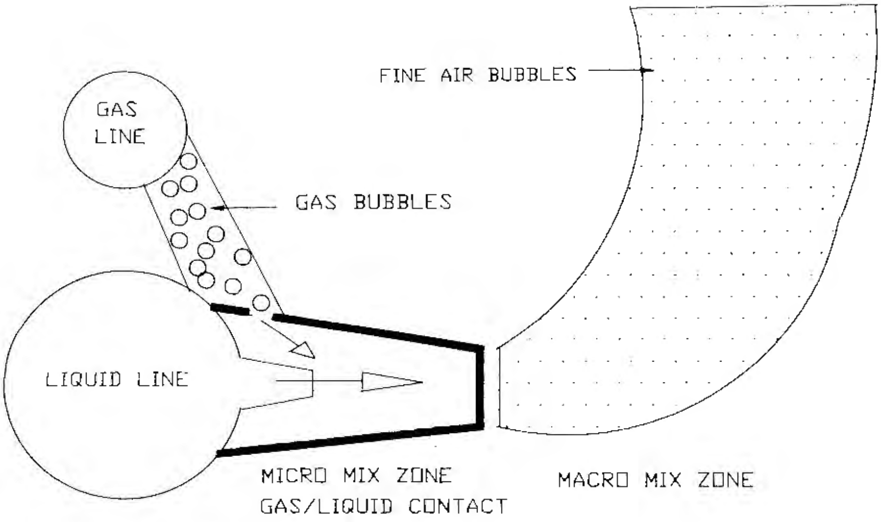

FIG 1
GAS / LIQUID CONTACTOR

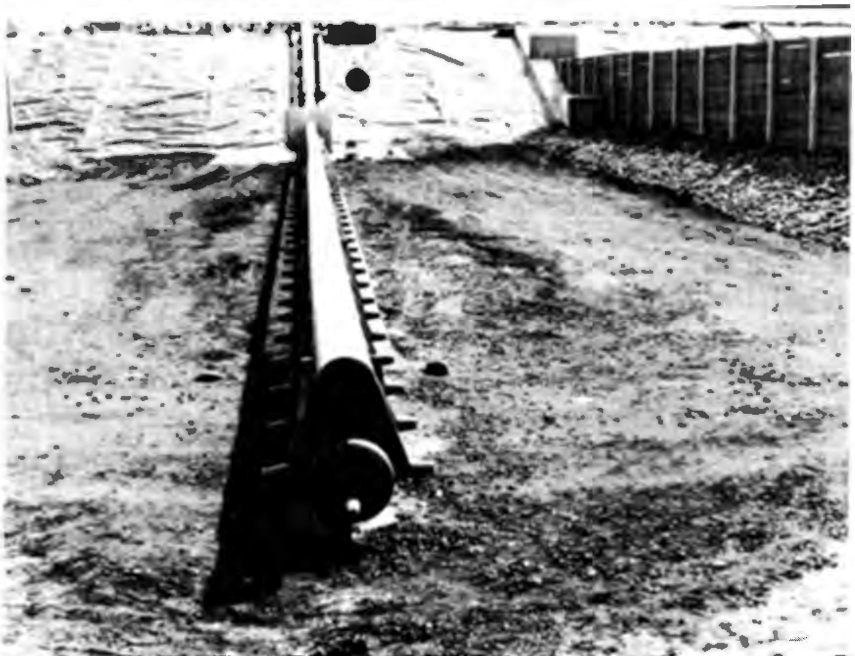

Fig. 2: Bi-Directional Jet Aerator

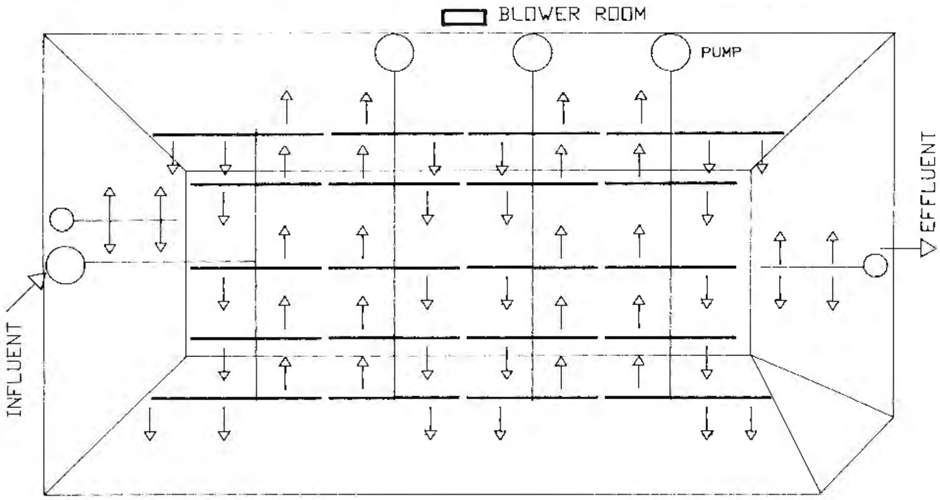

FIG 3
ARRANGEMENT AT FIBRECO HAS FOUR DISTINCT CELLS

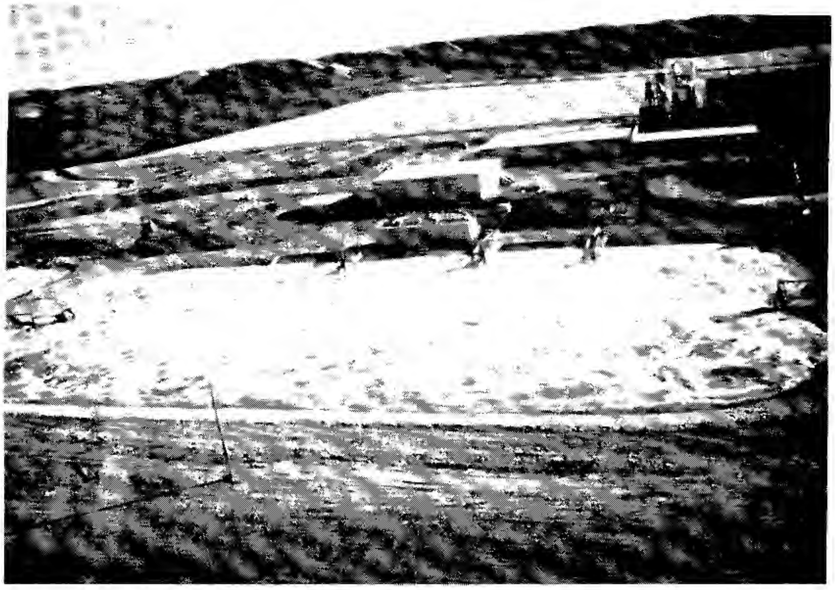

Fig. 4: Jet Aeration System in operation at Fibreco

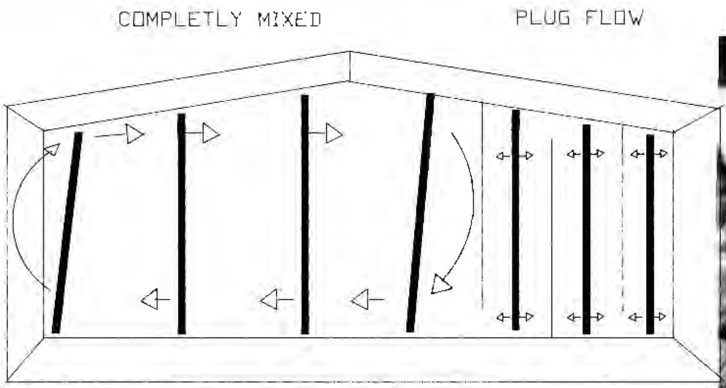

FIG 5

COMPLETELY MIXED AND PLUG FLOW REGIONS
MILLAR WESTERN PULP LTD

Fig. 6: Lagoon prior to being filled at Millar Western Pulp

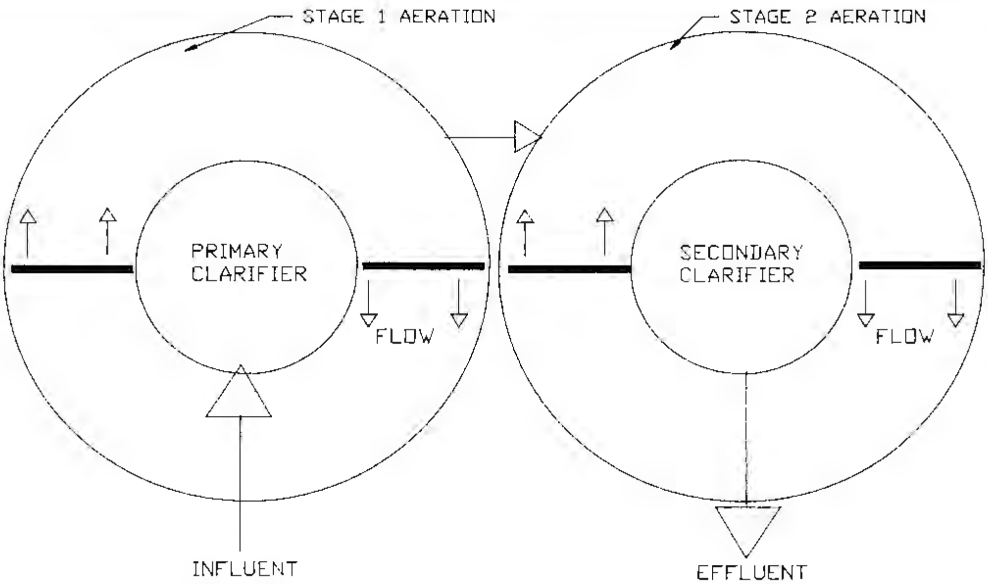

FIG 7

TWO STAGES IN SERIES OPERATION