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ENVIRONMENTAL AND WASTE MINIMIZATION ASSESSMENT

TO

JUHOSLOVENSKÉ CELULOZKY A PAPIERNE

ŠTÚROVO, SLOVAK REPUBLIC

JUNE 26 - 30, 1995

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I. INTRODUCTION

In June of 1995, Dr. Hans E. Wörster, pro bono specialist, Fletcher Challenge Canada Ltd., visited the Juhoslovenski Celulozky a Papierne A.S. - Papermill (JCP) located in the town of Sturovo in Southern Slovakia on the Danube River. The objective of the visit was to conduct an environmental assessment of the JCP plant and identify opportunities for pollution reduction and waste minimization.

Sponsorship of volunteer specialists like Dr. Hans E.Wörster is one of the many activities carried out by the World Environment Center within the framework of its Technical Assistance Program for Central and Eastern Europe, which is funded through the United States Agency for International Development. The World Environment Center acknowledges Dr. Hans E. Wörster, who gave freely of his time and expertise in assisting us in our work in Central and Eastern Europe.

II. EXECUTIVE SUMMARY

From June 26 to June 30, 1995, Dr. Hans E. Wörster, pro bono specialist, visited Juhoslovenske Celulozky a Papierne A.S. (JCP), located near Sturovo in the Slovakian Republic, to conduct an environmental assessment and to identify opportunities for waste minimization.

Dr. Wörster met with management, production and technical personnel and toured the manufacturing, energy generation and effluent treatment facilities as well as the mill's landfill area.

Based on information provided by mill staff and on observations made during the tours of individual mill areas etc., Dr. Wörster concluded that JCP:

- is utilizing raw materials efficiently and is losing very little fiber from the processing lines;
- is managing solid wastes very well;
- was meeting the current air emission limits during a test period in 1994 with the pulping chemical recovery system and with all power boilers, except that volatile organic emissions from one boiler (K5) burning wood waste exceeded the limits several times;
- is in compliance with the current effluent regulations **on the average**, but the highest effluent loads of 1994 were exceeding some of the limits.

Future emission limits that have already been announced are much stricter. Already in 1998, power boiler K5 would not meet the new limits on particulates when burning wood waste or fuel oil, on sulfur dioxide emissions when burning oil and on both carbon monoxide and volatile organics when burning wood waste. The existing cyclone for particulate removal would have to be replaced with more efficient separation equipment, e.g. an electrostatic precipitator. The combustion efficiency with wood waste would have to be improved to reduce the carbon monoxide and organic carbon content of the stack gas significantly. An analysis of the boiler's stack gas oxygen content, mixing efficiency of combustion gases with air and gas flow pattern would provide information for decision making for rebuilding the boiler.

For the other power boilers, new emission limits will be in effect in 1999. All boilers would not be in compliance with sulfur dioxide emission limits when burning brown coal and/or fuel oil due to the high sulfur content of these fuels. One of the boilers (K3) has already been rebuilt for burning gas and one more will be rebuilt. Sulfur dioxide emissions from these

boilers would then be negligible. Similarly, burning of anthracite (hard black coal) would reduce sulfur dioxide emissions.

Both sulfur dioxide and hydrogen sulfide emissions from the pulping chemical recovery area would exceed the 1999 limits. To reduce the emissions to the 1999 compliance level, some operating parameters of the recovery boiler need to be better controlled (primary and secondary air distribution and quantity as well as chemical composition of the spent liquor) and the existing Tampella chemical conversion system would have to be modified. To this end, a successful chemical system in operation at a mill in Finland should be visited by JCP's pulp mill manager.

Progressively stricter water pollution abatement regulations have also already been announced for the years 2003 and 2005. While the average 1994 chemical oxygen demand (COD) and total dissolved solids concentration would meet the 2003 limits, the 2005 limits on biochemical oxygen demand (BOD), chemical oxygen demand and total suspended solids would be exceeded significantly. Therefore, in-plant steps such as better pulp washing and collection of pulping liquor spills are planned to reduce the pollutant load to the effluent treatment plant. Furthermore, the existing effluent treatment system would have to be upgraded and expanded. At the time of the visit, only effluent flow and quality data for previous years, when paper production rates were not representative, were available. This data suggest too low dissolved oxygen and poor sludge settling for the biological treatment.

Data for the first half of 1995 are being compiled by JCP and will be sent to Dr. Wörster by the end of July for evaluation. The outcome of the evaluation will form the base for developing recommendations for decision making. They will be reported separately later.

Due to available land limitations, the future expanded effluent treatment system would have to be based on activated sludge technology. Anaerobic treatment technologies are not recommended due to poor operating experience in North America.

Due to the complexity and equipment intensity of pulp and paper manufacturing processes and the associated pollution abatement equipment, virtually all changes necessary at JCP for meeting future emission limits would have high **installed** capital cost. Most of them would probably exceed the $1,000,000 level.

III. WASTE MINIMIZATION TECHNIQUES

Waste minimization techniques being applied successfully by the pulp and paper industry in North America and in other countries with significant pulp and paper production, e.g. Sweden, Finland, and Brazil, include:

- management of raw materials such as wood, annual plants and waste paper in such a manner that losses and deterioration in shipping, preparation, storage and handling are minimized;

- careful handling of purchased fuels and of purchased on-site produced chemicals including efficient recovery of pulping chemicals to reduce losses;

- spill prevention and/or collection and recycling of pulp and paper stock slurries and of chemical solutions including spent pulping liquors;

- recovery of pulp/paper fibers and fillers from excess process water by settling or flotation techniques before sewering;

- reprocessing of off-grade paper production from the paper machines and converting operations by reslushing and blending in with the paper machine fiber furnish;

- efficient combustion of fuels to minimize emission of carbon monoxide and volatile organic compounds into the atmosphere and removal/recovery of sulfur dioxide from stack gases if sulfur rich fuel is used or elimination of sulfur rich fuels.

IV. FINDINGS

1. Description of the Plant Visited

1.1 Location

JCP is located on the North side of the Danube River close to the city of Sturovo in Southern Slovakia and approximately 150 kilometers East of Bratislava.

1.2 Ownership

JCP is owned 30% by the government of the Slovakian Republic and 70% by private investors.

1.3 Products and Processes

1.3.1 Products

JCP is producing a variety of paperboards for packaging materials, corrugated containers and roof and insulating materials using asphalt and modified asphalts.

1.3.2 Raw Materials

Virgin fiber raw materials are hardwoods, mainly local poplar and some birch imported from Russia as well as smaller quantities of local beech and oak for corrugating medium and spruce and pine for Asplund refiner pulp used for asphalt impregnation paperboard.

Waste paper in the form of mainly old corrugated containers (OCC) is another fiber raw material. Also some textile waste is utilized for paperboard production.

1.3.3 Total Paperboard Production

The total paperboard production capacity is approximately 100,000 metric tonnes/year of solid boxboard and 140,000 metric tonnes/year of corrugating medium (also referred to as fluting).

1.3.4 Recycled Fiber Plants and NSSC Pulp Mill

The production facilities include a recycled paper plant for converting OCC to fibers for fluting and another recycled paper plant for paperboards, a neutral sulfite semichemical (NSCC) pulp mill together with chemical recovery, an Asplund Defibrator plant, facilities for recovering fibers from old textiles, and three papermachines for the production of various paperboard grades (PM no. 1 and 2) and corrugating medium (PM 3).

Both the recycled fiber plant for corrugating medium and the NSSC pulp mill have a capacity of 300 tonnes pulp/day each. PM no. 1 and 2 are based almost entirely on recycled fiber.

The recycled fiber plants are the source of solid waste which consists of a large variety of different materials. These have no value and segregation into useful products is not economically feasible. Therefore, this waste is disposed of in a landfill.

The recycled fiber plants are using excess process water from the papermachines. A considerable portion of this process water is pumped from the recycled fiber operations to the effluent treatment plant.

1.3.5 NSSC - Pulp Mill Operating Conditions

In the NSSC pulp mill, screened wood chips are pulped with a solution containing sodium sulfite and sodium carbonate in a ratio of 3 to 1 and a total concentration of 100 grams/liter calculated as sodium oxide.

The chemical application based on the dry weight of the wood chips is 6% expressed as sodium oxide. The chips are first impregnated and then pulped for about 30 minutes at a temperature of 175 °C to 79-80% pulp yield in a Bauer M + D digester. The pulp chips are processed in 2 parallel Sund Defibrator refiners to 10-11 ° SR freeness. The resulting pulp is washed on a Chemi-washer to a residual spent liquor content (carry-over into the paper mill) of 42 to 45 kg/tonne on the average and is then pumped to the paper mill for further processing.

1.3.6 NSSC Pulping Chemical Recovery

The spent pulping liquor is concentrated from 10% to 58-59% solids content in a 5-stage Roseniev evaporation plant prior to further thickening to 61% solids in a cascade evaporator. The evaporator condensate is used for NSSC pulp washing.

The concentrated spent liquor is then fired in a Tampella chemical recovery boiler with approximately 70% primary air and 30% secondary air addition. The smelt leaving the boiler consists essentially of sodium carbonate and sodium sulfide. The latter has to be converted to sodium sulfite. This is accomplished with the Tampella sulfite recovery system in a number of steps and several reactors. They are described briefly below:

- scrubbing of the recovery boiler flue gas from the electrostatic precipitators with stripped process liquor to produce a solution containing sodium carbonate and sulfite;
- cooling of the scrubbed flue gas with cold water;
- precarbonation of the recovery boiler smelt solution with carbon dioxide of the flue gas to form sodium hydrosulfide and bicarbonate;

- stripping of hydrogen sulfide from the precarbonated liquor with sodium bicarbonate formed in the next stage;

- carbonation of the stripped liquor with carbon dioxide of flue gas to convert sodium carbonate to bicarbonate;

- cooling of the stripped hydrogen sulfide gas to remove moisture and separation of the resulting condensate which is contaminated with H_2S; the condensate is sewered;

- combustion of the hydrogen sulfide gas together with molten make-up sulfur in a sulfur burner to produce sulfur dioxide;

- absorption of the sulfur dioxide in the sodium carbonate - sulfite solution prepared by flue gas scrubbing and augmented with sodium carbonate make-up in an absorption tower to produce the sodium carbonate - sulfite NSSC pulping liquor.

Gas is released from the precarbonation stage, the carbonation stage and the pulping liquor absorption tower. This gas usually flows to a stack for subsequent release into the atmosphere.

It is obvious from the above brief description that the Tampella recovery process is very complex and that shortcomings of one of the process steps can cause serious problems in one of the above stages.

1.4 Employees

JCP had approximately 2760 employees in 1994. A large number of them have technical education and/or technical training.

2. Description of Environmental Issues

2.1 Air Pollution

2.1.1 Manufacturing Process

2.1.1.1 Particulate Emissions

The current limits on particulate emissions (mg/Nm^3) are not exceeded within the various manufacturing processes, on the average.

2.1.1.2 Gaseous Emissions

(a) NSSC - Pulping and Chemical Recovery

The current limits on sulfur dioxide (SO_2), hydrogen sulfide (H_2S), nitrogen oxides (NO_X) and carbon monoxide measured as mg/Nm^3 are higher than the actual performance of JCP. However, the long term limit of SO_2, which comes into effect on January 1, 1999, would be exceeded considerably (700 compared to 3045 mg/Nm^3 on the average.) Also the long term limit of hydrogen sulfide (H_2S) would not be met (average of 206 compared to 40 mg/Nm^3).

Within the NSSC pulping and chemical recovery plant, the emission sources of H_2S and SO_2 are located in the pulping liquor preparation area. They are apparently mainly due to poor design by the supplier and also due to leaks of the equipment which are probably a result of corrosion.

(b) Oxidation of Asphalt

In the oxidation of asphalt used for special asphalt impregnated roofing tiles, the emissions of SO_2, H_2S, NO_X and CO are not exceeding the present limits.

New limits have been announced only for H_2S and they will be in effect as of January 1, 1997. The current emissions of H_2S are exceeding the 1997 limits slightly on the average, e.g. 13 and 16 mg/Nm^3 compared to 10mg/Nm^3 limit.

2.1.2 Power Boilers

2.1.2.1 Particulate Emissions

The particulate emissions from all five power boilers are far below the current limits. The long term limits, which will be in effect as of January 1 1999, would be met by the current emissions from power boilers K1, K3 when burning natural gas and K4. Power boiler K2 would exceed the long term limits slightly (108 compared to 100 mg/Nm^3). But it will be taken out of operation.

The long term (1999) limits would be exceeded with power boiler K3 when burning heavy heating oil.

For power boiler K5, new limits will be in effect on January 1, 1998. This boiler would not meet these limits, both when burning wood waste or heavy heating oil. It seems that the mechanical ash separation device of K5 will not be capable of removing the particulate to the new long term limit.

2.1.2.2. Gaseous Emissions

All five power boilers are meeting the current limits on SO_2, NO_X and CO. When boiler K5 is burning wood waste, it also has to meet a limit of 50 mg of organic carbon/Nm^3. However,

the average performance value is 373 mg/Nm^3. This discrepancy suggests incomplete combustion.

New limits will be in effect as of January 1, 1999. All boilers would meet the CO emission limits under the present operating conditions with non-wood fuels. But Boiler K5 would meet the CO limit only when burning heavy oil but not with wood waste.

None of the five boilers would meet the 1999 SO_2 limits except for boiler K5 when burning wood waste. The sources of the SO_2 are low quality high sulfur content brown coal and heavy fuel oil. The continued use of these two fuels would require removal of SO_2 from the boiler stack gases. One alternative would be wet scrubbing, e.g. with sodium carbonate. This would provide a solution of sodium sulfate and sulfite, which may also contain a small amount of sodium nitrate and/or nitrite and bicarbonate. Only the sodium sulfite would be useful for pulping. Furthermore, the installation of a wet scrubber would require considerable capital. However, it would also allow heat recovery in the form of warm and hot water.

Regular black coal could be an alternative to low quality brown coal due to its lower sulfur content and higher calorific value. Obviously, the ideal fuel is natural gas due to its extremely low sulfur content.

The 1999 limits on NO_X emissions would be met by power boiler K1 and K2. Boiler K5 would meet its 1998 limits on NO_X emissions both with woodwaste or oil as fuel.

2.2 Water Pollution Based on 1994 Performance

The treated effluent discharged into the Danube in 1994 met the current limits (valid until the end of 2002) on biochemical (BOD) and chemical oxygen demand (COD), on suspended (TSS) and on dissolved solids(DS) concentrations on the average. The average concentration of oil was slightly below the limit. The total output of these pollutants expressed as tonnes/year was also meeting the current legal requirements, although the maximum concentration values were exceeding the limits.

Stricter regulations will be in effect during the years 2003 and 2004 and even more stricter regulations from January 1, 2005. The 1994 average concentrations of the pollutants would not meet the BOD limits for the years 2003 and 2004, and especially not those of January 1. 2005. Similarly, the COD concentration limits of January 1, 2005 and the TSS concentration limits for 2003 and subsequent years would not be met with the 1994 effluent.

With regard to tonnes of pollutants discharged per year, the 1994 BOD load would exceed the limits for 2003 and subsequent years.

2.3 Solid Waste

Some of the solid waste generated by the plant is either recycled or reused for other purposes. The major portion of unused solid waste is ash and clinker from coal burning. This material is inert and does not present a hazard.

Almost all hazardous waste is either incinerated at the plant or rendered harmless elsewhere or even recovered for re-sue, e.g. trichloroethylene by distillation.

Other solid waste, e.g. residue from waste paper processing, is disposed of in a landfill because its composition is so complex that it cannot be utilized in any known way.

2.4 Control Systems

2.4.1 Air Emission Control

The Tampella chemical recovery boiler is equipped with electrostatic precipitators. The boiler flue gas then serves as source of carbon dioxide in the Tampella sulfite recovery system described in section 1.3.6. Thus the flue gas is scrubbed and its sulfur dioxide content is also utilized. At JCP, the boiler flue gas contains up to 3000 mg SO_2 and up to 1000 mg H_2S/Nm^3.

Amongst the six power boilers, number K1. K2, and K4 have electrostatic precipitators and K5 has a mechanical ash separator consisting of 108 cyclones with 300 mm diameter. K3 was rebuilt in 1992 to burn natural gas.

Boilers no. K1 and K2 have common precipitators and are not operated simultaneously. After cleaning in the precipitators, the stack gas from K1 or K2 is tested continuously for particulates with an Erwin Sick analyzer and for chemical composition with the Rosemount procedure. Stack gas from the other boilers is tested with portable equipment.

2.4.2 Effluent Control

Effluent treatment consists of primary sedimentation, low rate activated sludge treatment, secondary sedimentation and thickening of primary sludge together with excess sludge from the activated sludge system. The thickened sludge is used in agriculture.

Effluent from the individual mill departments is treated as follows:

a) No. 1 and no. 2 paper machines and their stock preparation systems effluent is pumped to a common settling tank for removal of suspended solids. After sedimentation, it is combined with biologically treated effluent from the other mill departments and discharged into the Danube river through a submerged pipe.

b) No. 3 papermachine's and its stock preparation effluent are combined with the effluent from the NSSC pulp mill and pumped to a separate sedimentation tank. After sedimentation,

half of this effluent is sewered directly into the Danube river due to limited hydraulic capacity of the biological effluent treatment system. The other half is treated in the activated sludge system.

c) Effluent from the chemical recovery plant of the NSSC mill is pumped directly to the biological treatment system without sedimentation because it is virtually free of fibers.

The combined effluent from the biological treatment, from papermachines no. 1 and no. 2 sedimentation tank and the half of the effluent described in section (b) above that by-passes the activated sludge systems is discharged into the Danube river at a point referred to as discharge point A.

Effluent from the landfill area, which is essentially transport water for boiler ash, is discharged into the Danube separately at discharge point B.

Retention time of the effluent in the activated sludge system is 24 to 36 hours. The system consists of three parallel lines with eight surface aerators each (total of 24) with 15 kW motors. Secondary sludge recycle to the biological treatment system is 150% of the volume of the effluent to be treated. In the aeration stage, the effluent contains only 2.5 to 3 mg dissolved oxygen/liter compared to a target of 3 to 4 mg/l. It has a characteristic anaerobic smell. Excess sludge from the secondary clarifiers is thickened in an Andritz press to 20% solids and then used in agriculture. The sludge settles poorly, i.e. it has a very high sludge volume index (SVi) of 150 to 200 ml/g compared to a target of less than 80 ml/g for a well settling sludge and approximately 50 ml/g for a sludge with excellent settling rate. According to the engineer responsible for the effluent treatment technology, the sludge contains a high portion of filamentous organisms. They are known to affect sludge settling adversely. Predominant growth of filamentous organisms can be caused by a variety of conditions. They include:

- low dissolved oxygen content (DO);
- low food to microorganism ratio (f/m);
- septic waste water, e.g. presence of sulfide;
- nutrient deficiency;
- low pH.

The most likely of the causes are discussed in section V "Conclusions and Recommendations."

The regulations issued by the Administrator of the Danube river require sampling and testing of the discharge to the Danube 52 times per year. However, JCP is taking a sample every 55 minutes over 24 hours with an automatic sampler. A composite sample of the 24 hour period

is tested by mill technicians, who were trained by the Administrator of the Danube, five or six times a week. At times, the Administrator also take samples for testing.

Effluent discharged at point B is tested every second week.

The 1993 annual test averages were as follows:

DISCHARGE POINT	A	B
Pollutant, mg/l		
Suspended Solids	440	50
Dissolved Solids	1150	1150
BOD_5	225	30
COD	690	50
Oil	5	-
pH	7	-

For the biological treatment, the data indicate only 73% reduction of BOD and 38% reduction of COD on the average for 1993 compared to maximum values of 80-90% and 60-65% respectively reported in the literature for the activated sludge stage. A discharge fee based on the BOD discharge has to be paid by the mill.

In the year 2003, stricter effluent regulations will come into effect. It is expected that, at that time, all effluent will have to be treated biologically. JCP's biological effluent treatment system would then have to be upgraded or expanded.

2.4.3 Solid Waste

JCP has a 15 hectare area for waste disposal adjacent to the mill. The area is protected by a fence.

Solid waste is well managed. Much of the organic waste is incinerated either at JCP or elsewhere. Solid waste form waste paper recycling is a very heterogenous mixture of a variety of materials and is disposed of in a landfill in an orderly manner.

Boiler ash is transported with river water through a pipe system to a landfill area adjacent to the mill. A considerable portion of this particular landfill is already full. It is covered with sludge from the mill's effluent treatment plant. A large area that was closed out and covered approximately two years ago has already two to three meters tall growth of various shrubs and

trees which appeared to be thriving. An example is shown in a photo included in the appendix.

Wells for taking groundwater samples for testing have been installed.

The combined sludge from the effluent treatment system has also been used successfully in agriculture.

The fine carbon dust from the precipitators of power boilers K1 and K2 is used by a cement factory located in Hungary.

2.5 Control or Remediation Programs in Progress, Planned or Recommended

2.5.1 Air Pollution Abatement

Mill personnel is proposing the replacement of the existing NSCC spent liquor evaporation plant by a new evaporator set and by concentrators because the existing equipment is obsolete. A new plant would be designed in such a manner that air pollution from the downstream chemical recovery equipment would be very much reduced. However, the installation cost is estimated to be approximately US $35 Million.

It is recognized that brown coal and heavy fuel are the main sources of sulfur dioxide emission from the power boilers. JCP's plan is to burn black coal in boiler K1 and to shut down boiler K2. Boiler K3 has already been rebuilt to burn natural gas. The same change is planned for boiler K4.

At the time of the visit, no plans appeared to exist for upgrading the environmental performance of boiler K5 when it burns wood waste.

2.5.2 Water Pollution Abatement

The carryover of 42 to 45 kg dissolved solids per tonne of washed NSSC pulp into the paper mill must increase the BOD and COD load of the paper mill effluent considerably. It also increases the quantity of make-up pulping chemicals needed. To reduce the carryover, the installation of a wash press after the existing Chemiwasher has been recommended. This project would cost approximately US $1.5 Million and, according to a supplier, would reduce the carryover to 6-7 kg/tonne NSSC pulp. As a result, BOD and COD load to the effluent treatment system should be reduced significantly. Quantitative information on the potential BOD and COD reduction is not available.

A spill collection system for pulp mill liquors is being installed for start-up in September 1995. It would reduce BOD and COD of the pulp mill effluent and also reduce chemical make-up and steam cost somewhat. Small spills of pulp are already reclaimed and returned to the pulp washer.

There appear to be no immediate plans for upgrading the effluent treatment system.

V. CONCLUSIONS AND RECOMMENDATIONS

A. Air Pollution Abatement

1. The available test results indicate that in the future stricter regulations on SO_2 and H_2S emissions from the NSSC chemical recovery system cannot be met unless some significant changes in operating procedures and/or equipment are made. Currently, a major problem is the high concentration of H_2S (up to 1000 mg/Nm^3) in the recovery boiler flue gas. It is probably caused by poor control of the excess oxygen content of the flue gas. The distribution and amounts of primary and secondary air are also important parameters. Close to zero emission of total reduced sulfur is possible by proper management of the air flows (Appendix E-3). For control of SO_2 emissions from the recovery boiler, a proper sodium to sulfur ration must exist in the spent pulping liquor. Also high solids firing reduces SO_2 emissions but usually increases the particulate emissions.

A continuous gas analyzer is not available and therefore the volume of combustion air cannot be adjusted continuously to maintain 3 to 4% excess oxygen which would virtually eliminate H_2S. Flue gas contaminated with H_2S results in the formation of sodium hydrosulfide (NaHS) in the alkaline liquor. Together with SO_2, sodium thiosulfate may be formed and H_2S is emitted from the stack of the SO_2 absorption tower where the pulping liquor is generated.

2. Also, the carbonation stage of the Tampella recovery system installed at JCP is apparently underdesigned and therefore does not have the capacity to generate enough sodium bicarbonate for efficient H_2S stripping. As a result, the feed liquor to the SO_2 absorption tower contains sodium sulfide, which is then emitted from the absorption tower as H_2S. A more recent installation at Oji Paper Co. in Japan has a larger carbonation stage and the system is apparently functioning well.

JCP needs proof that the carbonation stage of their chemical recovery system is indeed underdesigned and does not efficiently convert the carbonate to provide the required quantity of bicarbonate. A mill trial with the use of additional purchased bicarbonate could provide the answer. If the trial is positive, JCP would have justification to increase the capacity of the carbonation stage.

3. The Heinola NSSC corrugating medium mill of Enso Gutzeit Corporation, Finland has been successfully operating a chemical recovery system similar to that of JCP. It is known as the Rauma Repola Oy system. A schematic is shown in Appendix E-2. The major differences are a pH of 13 in the precarbonation stage, the addition of CO_2 gas in a pressure absorber ahead of the stripping tower and very little sodium sulfide (0.0 to 0.03 gpl as sulfur) in the stripped solution, which contains essentially sodium carbonate. The overall result is an extremely low emission of H_2S from the system.

JCP would have to add the CO_2 absorber between the precarbonator and the H_2S stripper and needs to ensure that the stripper has sufficient capacity.

Mr. Stefan Csaladi, Manager of the JCP NSSC pulp mill and chemical recovery, should visit the Heinola mill in order to witness the recovery operation and to assess the potential of converting JCP's sodium sulfite recovery plant to the Rauma Repola system.

4. When burning wood waste in no. 5 power boiler, the stack gas considerably exceeds the 1998 limits on particulate matter, CO and organic carbon (VOC). For meeting the particulate limit alone, a much more efficient separation device than the cyclone currently in use would be required. An electrostatic precipitator would probably be the technically most effective solution.

It is very likely that the particulates consist mainly of incompletely burned wood material. Also the high CO and volatile organic carbon content of the gas must be due to incomplete combustion. There is no documented data on the oxygen content of the stack gas. Apparently, it is 18 to 19%. This verbal information has to be confirmed by measurements. If correct, combustion in the presence of so much oxygen suggests poor mixing of the fuel above the bed with the combustion air, severe channelling or combustion zone cooling. A rebuild of the boiler may be required. The optimum design for the rebuild would have to be based on some gas velocity measurements and chemical gas analysis over cross sections of the boiler. More details are presented in Appendix E-4.

5. Test results established in July to October 1994 on boilers K1, 2, 3, and 4 when burning brown coal or fuel oil showed much higher emissions of SO_2 than the 1999 limit. Both of these fuels have high sulfur contents. Dry scrubbing of the stack gas with lime would reduce the SO_2 content significantly but this approach would require considerable capital expenditure and would also generate solid waste (calcium sulfite) which would have to be disposed of. The obvious solution would then be to use low sulfur content fuels although they are more expensive.

Replacement of brown coal with black coal and/or conversion to gas firing as already completed with boiler K3 would be technically correct solutions.

6. Tests conducted with the asphalt oxidation system in October 1994 when both condensator oil and heavy oil were fired indicated high sulfur dioxide emissions and marginally higher H_2S emissions than would be allowed by the 1997 regulations. Use of oil with low sulfur content would be necessary.

B. Water Pollution Abatement

1. In 1994, the existing limits of the effluent parameters were met by the effluent discharged into the Danube.

2. A large portion of the mill's effluent is currently not treated in the activated sludge system due to the hydraulic limitation of the system. However, in 2003 all mill effluent has to be processed efficiently in a biological treatment system.

3. The 1994 actual maximum discharge concentrations of BOD, COD and dissolved solids of the treated effluent would exceed the stricter limits which will be in effect in 2003.

4. Still stricter BOD and total suspended solids effluent limits of 2005 would not be met by the 1994 values of the treated effluent.

5. Significantly better washing of NSSC pulp than currently possible and collection of NSSC liquor spills as already discussed in section 2.5.2 of the Findings would not only recover valuable chemicals but would also reduce the BOD and COD load to the effluent treatment system. These in-plant improvements are therefore supported.

At my request, JCP will analyze the spent liquor carried over to the papermill with the NSSC pulp for BOD and COD so that the environmental benefit of better pulp washing may be quantified.

6. From points 2 to 4 above, it follows that the existing effluent treatment system needs to be upgraded or expanded. The 1993 average test results for the existing activated sludge system indicate only 38% and 73% removal efficiency for COD and BOD respectively with the effluent volume treated, which presented only approximately 25% of the total effluent.

7. Only limited test results are available on the condition of the existing effluent treatment system. The data on dissolved oxygen (DO) content in the system are old because the DO meter is not in workable condition. The old data indicate only 2.5 to 3 mg DO/l and this is too low for efficient BOD and COD removal. It is absolutely necessary that DO be measured because it is a key parameter. Some details on DO measuring system configurations are presented in the Appendix.

The low DO content could also be responsible for the predominance of filamentous growth in the sludge and its high sludge volume index (SVi).

Similarly, insufficient data appears to be available for determining the food/microorganism ratio (f/m), which is another important parameter of the activated sludge system.

The 1993 and 1994 data on effluent quality are of limited value because paper production rates and therefore the loads to the effluent treatment system were not representative. Therefore, the test results of the first half of 1995 (representative production rates) are being compiled for H.E. Wörster by JCP so that he can develop concrete recommendations for upgrading and expanding the existing treatment system.

8. In the absence of sufficient meaningful data, only preliminary recommendations can be submitted. They are as follows:

- maintain the existing sedimentation and activated sludge treatment system and upgrade it, especially the operating conditions of the activated sludge system; for optimization, good test data need to be generated, e.g. DO, f/m etc.;

- the hydraulic load to the existing system would probably have to be reduced significantly to meet the long term limits on BOD, COD, suspended and dissolved solids; reliable performance data (many still to be generated) would be the basis for estimating the maximum hydraulic load;

- build an additional system for the effluent volume that is currently not treated biologically and for the excess load of the existing activated sludge system; an anaerobic process cannot be recommended due to its poor reliability and very long recovery period after upsets; an aerated lagoon is not feasible due to limitations of available land;

- the additional biological treatment system would have to be another activated sludge system and it would have to be selected mainly on the basis of the volumetric BOD loading of the effluent to be treated. For example, a pure oxygen process works best with a 1.6 to 4 kg BOD/m^3 loading and has a BOD reduction efficiency of 85 to 95% with a hydraulic residence time of only 2 to 4 hours. The effluent from the NSSC pulp mill and chemical recovery is within the above BOD loading range. For very low BOD loadings, ie. 0.15 to 0.4 kg BOD/m^3, extended aeration with 18 to 24 hydraulic retention time would be best. BOD reduction efficiency may vary between 80 and 90%.

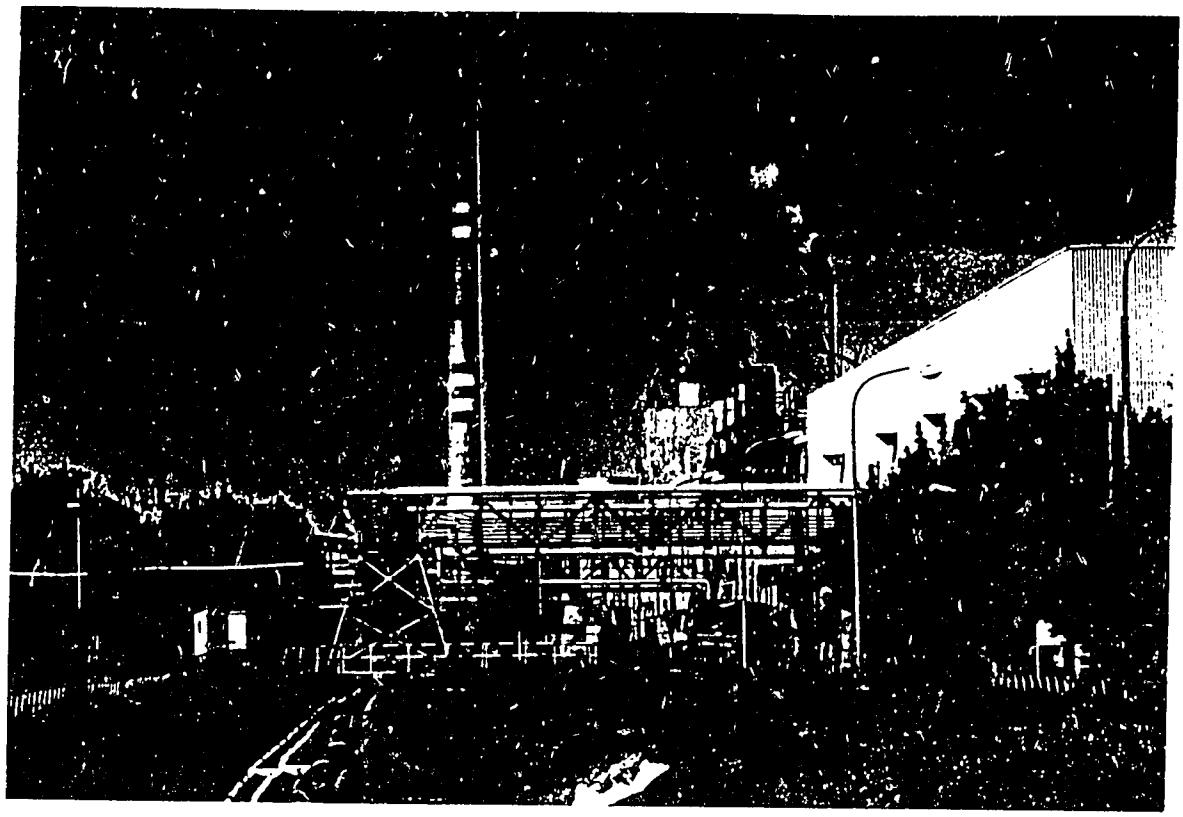
  The above two examples are given to illustrate the importance of reliable data on BOD loading of the individual process streams that have to be treated biologically.

9. A low capital cost variant of activated sludge treatment technology is the so-called "Sequencing Batch Reactor". All steps of effluent treatment including sludge settling are conducted in the same reactor. As a result, secondary clarifiers are not needed and installed system cost may be up to 30% lower than for conventional process equipment. Very high efficiencies of BOD and suspended solids removal have been claimed by the supplier, e.g. down to 30 mg/l BOD and suspended solids in the final effluent.

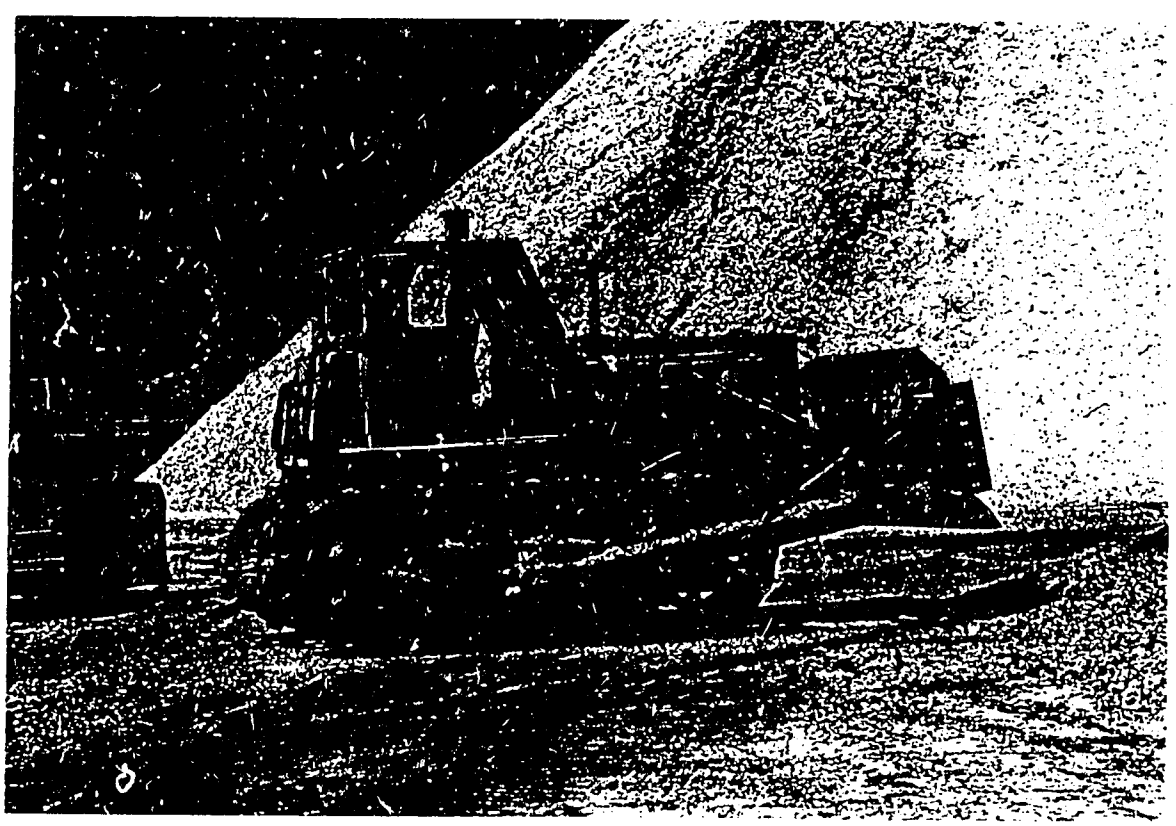
VI. APPENDICES

APPENDIX A

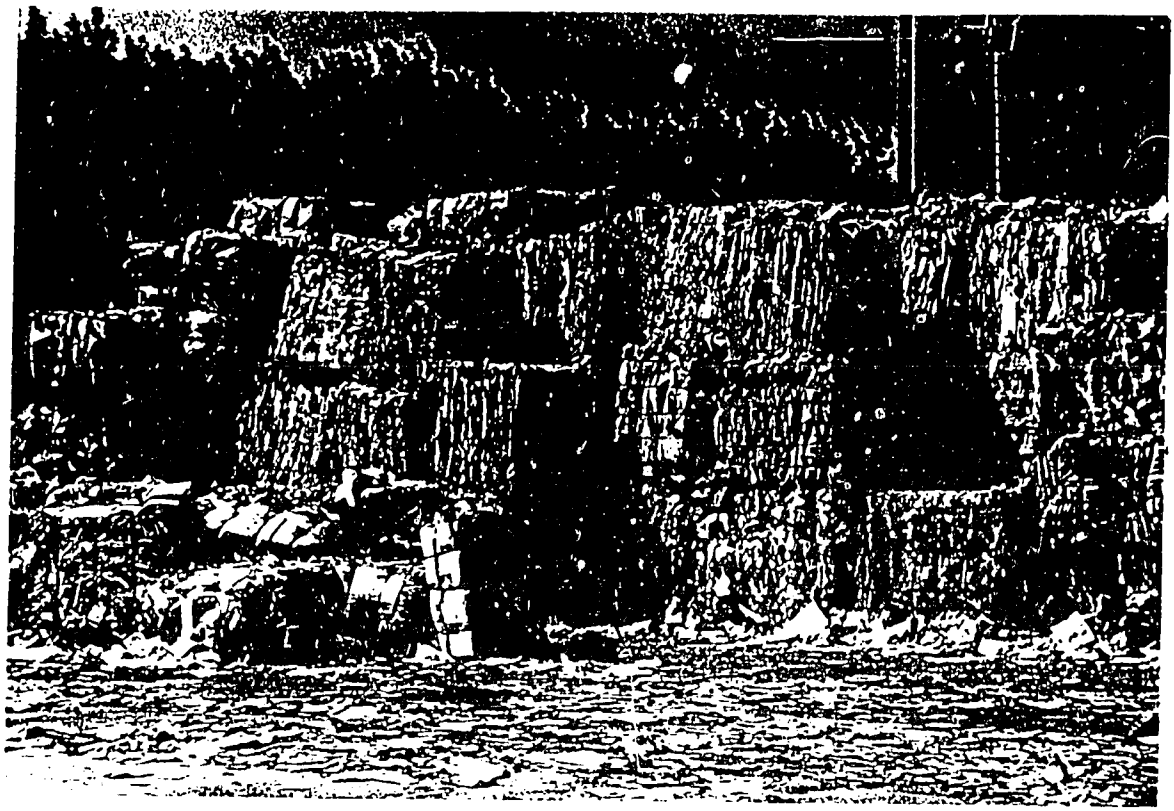
PHOTOGRAPHS



VIEW OF MILL



WOOD CHIP PILE AND TRACTOR RECL ' IMING CHIPS

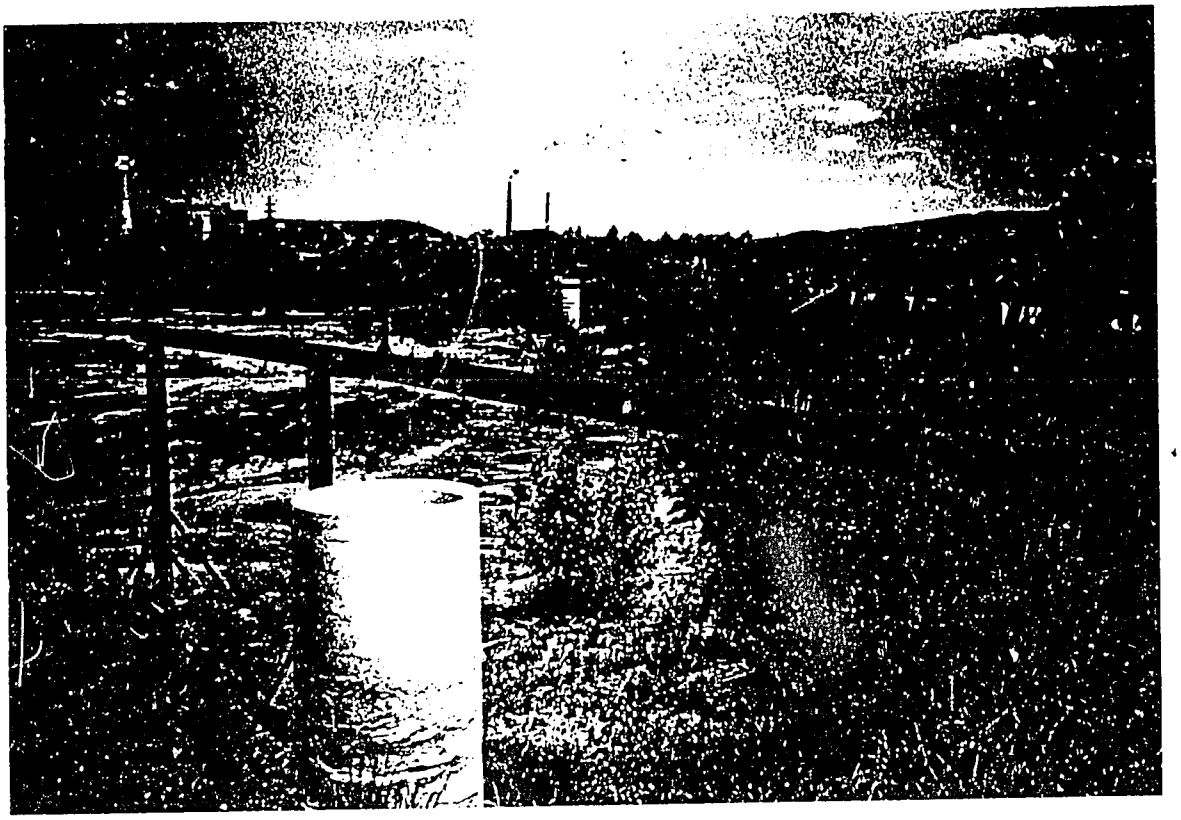


WASTE PAPER STORAGE - BALES

WASTE PAPER - LOOSE, READY FOR BEING PROCESSED

EFFLUENT TREATMENT SYSTEM WITH PART OF THE MILL IN THE BACKGROUND

AERATORS OF EFFLUENT TREATMENT SYSTEM



LANDFILL AREA FOR BOILER ASH - PIPE SYSTEM FOR DISCHARGING ASH SLURRY

FILLED LANDFILL AREA COVERED WITH EFFLUENT SLUDGE

CLOSED OUT LANDFILL COVERED WITH EFFLUENT TREATMENT SLUDGE AND GROWN OVER WITH SHRUBS AND TREES - 2 YEARS OLD

APPENDIX B

ITINERARY - VISIT OF J.C.P. STUROVO

DATE	ACTIVITY
June 26	· Travelling from Bratislava to Sturovo · General introduction to staff of section of Environmental Protection (SEP) and introductory meeting on types and sources of major wastes · Overview tour of entire plant
June 27	· Tour of NSSC pulp mill, chemical recovery area and effluent treatment plant and meetings with pulp mill manager and water and effluent plant supervisor; also tour of the corrugating medium paper machine
June 28	· Detailed meeting with engineers and operators responsible for the effluent treatment plant and tour of the two paperboard machines, their raw material preparation areas and of the paperboard conversion plants including the corrugated container plant
June 29	· Tour of wood preparation area, power boilers, asphalt preparation plant, landfill area and activated sludge system
June 30	· Collection of technical data and flow sheets and meetings with environmental engineers and engineering director and general manager · Return trip to Bratislava

APPENDIX C

LIST OF PERSONS MET WITH AND THEIR BUSINESS CARDS

Dipl. - Ing. JURAJ KUČERA, CSc.
Generaldirektor
General Manager

Juhoslovenské celulózky a papierne š. p. Štúrovo
Továrenská 1
943 03 Štúrovo
Tel.: (0810) 20 00, 34 83, 611 kl. 31 00
Telex: 098 438, 098 439
Fax: (0810) 48 87

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Ing. Vladimír BENDÍK
technický riaditeľ — technischer Direktor
Engineering and Technical Director

☎ 0810 / 611
0810 / 2010
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FAX: 0810 / 3480, 4886

JUHOSLOVENSKÉ CELULÓZKY A PAPIERNE, a. s.
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Ing. Eduard HADERKA
vedúci odboru ochrany životného prostredia
Manager, Environmental Protection

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Mgr. no. 1 + 2 Paper Machine

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TELEFAX: 0810/3480, 4887

KOMENSKÉHO 133
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TEL. 0810/3143

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Dipl. Eng. Rudolf ERDŐS
[redacted] Technical Manager Factory 02 (Fluting)
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TELEFAX: 0810/3480, 4887

JUHOSLOVENSKÉ CELULÓZKY A PAPIERNE
943 03 ŠTÚROVO, SR

Štefan ČSALADI

JUHOSLOVENSKÉ CELULÓZKY A PAPIERNE
943 03 ŠTÚROVO, ČSFR

Ing. ALEX IVANČO
(Retired)
Consultant to the General Manager, Interpreter

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Telefax: 0810/3480, 4887

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Water + Soil Protection Engineer

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SEP
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943 03 ŠTÚROVO, SR

Ing. Štefan GODÓ

Effluent Treatment Plant Manager

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FAX: 0810 / 3480, 2010

JUHOSLOVENSKÉ CELULÓZKY A PAPIERNE
943 03 ŠTÚROVO, ČSFR

Ing. JINDŘICH FALTYS

Quality Supervisor (ISO 9000 etc)

☎ 0810/2184
0810/611
Telex: 098 438, 098 439
Telefax: 0810/3480, 4887

Eva Zvoncsárová
Übersetzerin
Interpreter

Juhoslovenské celulózky a papierne, a. s., 943 03 Štúrovo
Tel.: (0810) 611, kl. 31 26, Telex: 098 438, 098 439
Fax: 42/810/48 87, 34 80

APPENDIX D

LIST OF DOCUMENTS RECEIVED

1. Test results on gas emissions from power boilers - 1994 test series
2. Sankey diagram of effluents - 1991 and 1992
3. Effluent quality data - 1993 averages and maximum values
4. Mill layout map
5. Sewer map
6. Current and future air emission and effluent limits and 1994 average test results

APPENDIX E - 1

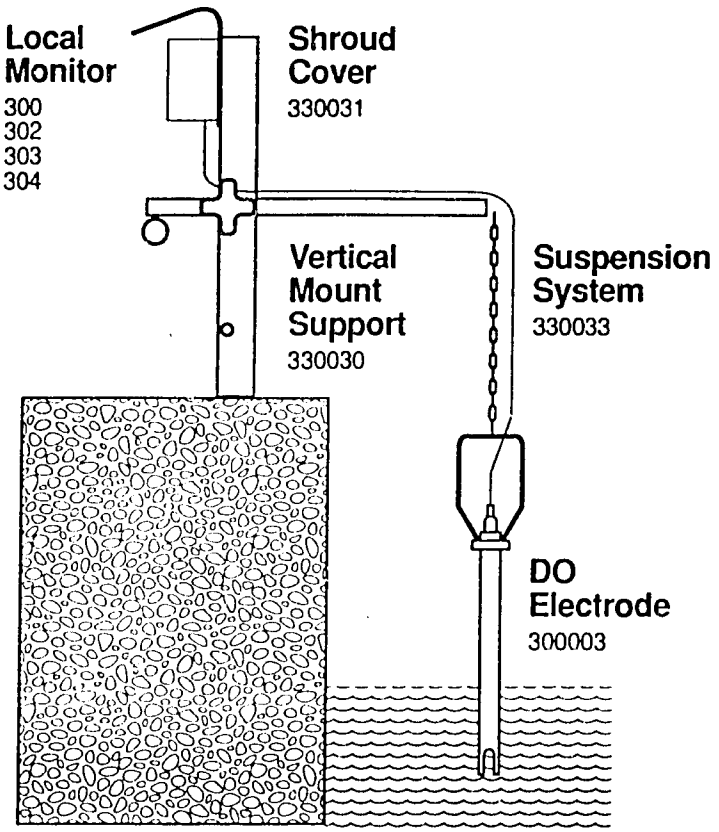
RECOMMENDED DISSOLVED OXYGEN SYSTEM CONFIGURATIONS

Recommended Dissolved Oxygen System Configurations

Appendix E-1

Orion Research Incorporated
Process Monitoring Group
The Schrafft Center, 529 Main Street
Boston, MA 02129
Tel: 1-800-225-1480 Fax: 1-617-242-4195 Form DO SYS CON/0930

ORION



System 1: Dissolved Oxygen Tank Side Oscillating Suspension System (Local Monitor)

Includes:

(QTY)

(1)❑ Model 300 (Cat. # 330001)
Digital display, manual calibration and barometric pressure correction.
or

❑ Model 302 (Cat. # 330201)
Same as Model 300 with alarm set points.
or

❑ Model 303 (Cat. # 330301)
Microprocessor, O_2 and temperature digital display, auto calibration and barometric pressure correction.
or

❑ Model 304 (Cat. # 330401)
Same as Model 303 with alarm set points.

(QTY)

(1)❑ Shroud Cover (Cat. # 330031)

(1)❑ Electrode with 21' Cable (Cat. # 300003)

(1)❑ Electrode Service Kit (Cat. # 300051)

(1)❑ Vertical Mount Support (Cat. # 330030)

(1)❑ Electrode Suspension System (Cat. # 330033)

Please use boxes to check off items to be quoted

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Process Monitoring Group
The Schrafft Center, 529 Main Street
Boston, MA 02129
Tel: 1-800-225-1480 Fax: 1-617-242-4195

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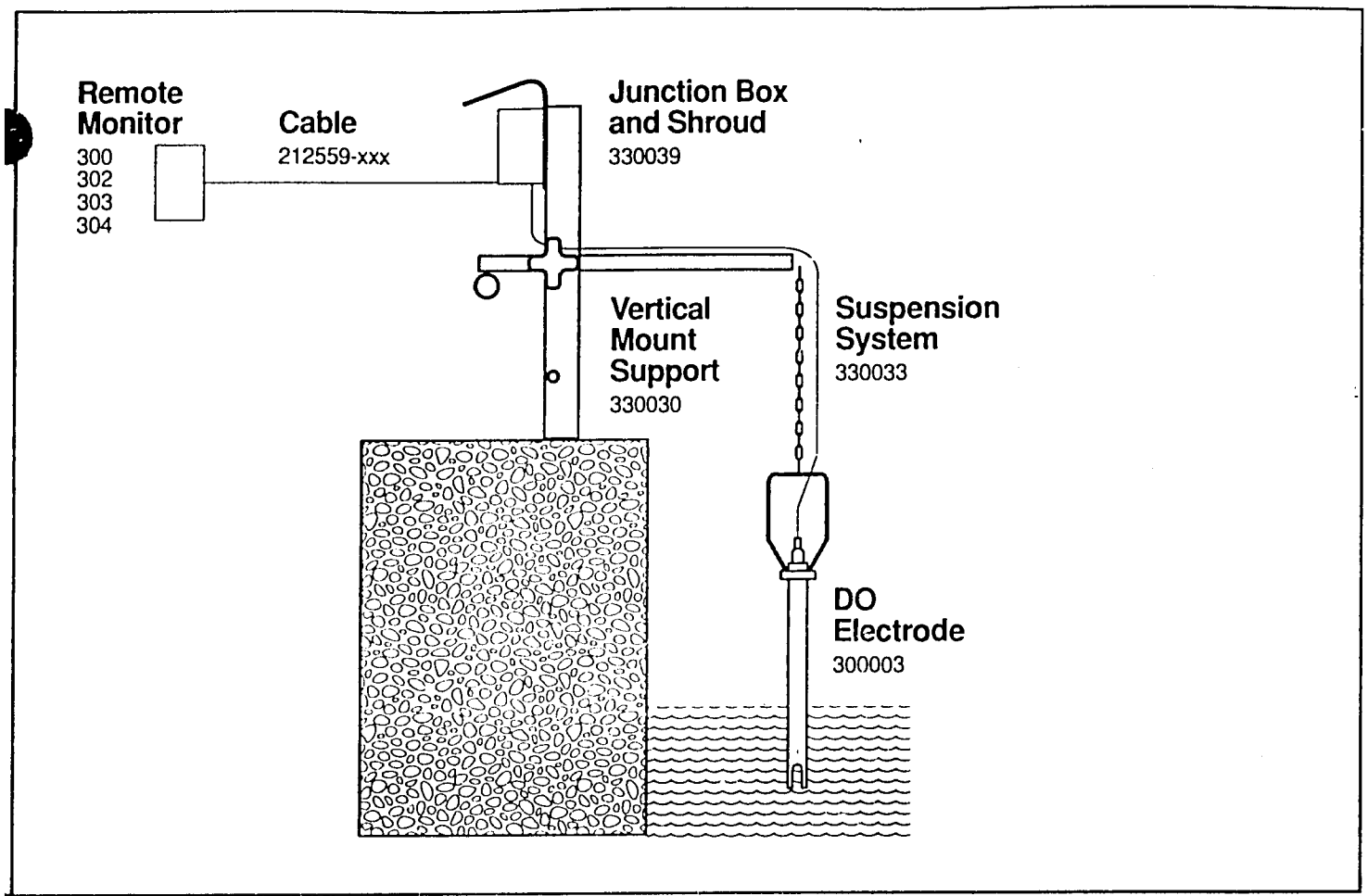

System 2: Dissolved Oxygen Tank Side Oscillating Suspension System (Remote Monitor)

Includes:

(QTY)

(1)❑ Model 300 (Cat. # 330001)
Digital display, manual calibration and barometric pressure correction.
or
❑ Model 302 (Cat. # 330201)
Same as Model 300 with alarm set points.
or
❑ Model 303 (Cat. # 330301)
Microprocessor, O_2 and temperature digital display, auto calibration and barometric pressure correction.
or
❑ Model 304 (Cat. # 330401)
Same as Model 303 with alarm set points.

(QTY)

(1)❑ Junction Box and Shroud (Cat. # 330039)
(1)❑ Electrode with 21' Cable (Cat. # 300003)
(1)❑ Electrode Service Kit (Cat. # 300051)
(1)❑ Vertical Mount Support (Cat. #330030)
(1)❑ Electrode Suspension System (Cat. # 330033)
(1)❑ Cable 10' (Cat. # 212559-010)
or
❑ Cable 25' (Cat. # 212559-025)
or
❑ Cable 50' (Cat. # 212559-050)
or
❑ Cable 100' (Cat. # 212559-100)
All cables include watertight plugs.

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Boston, MA 02129
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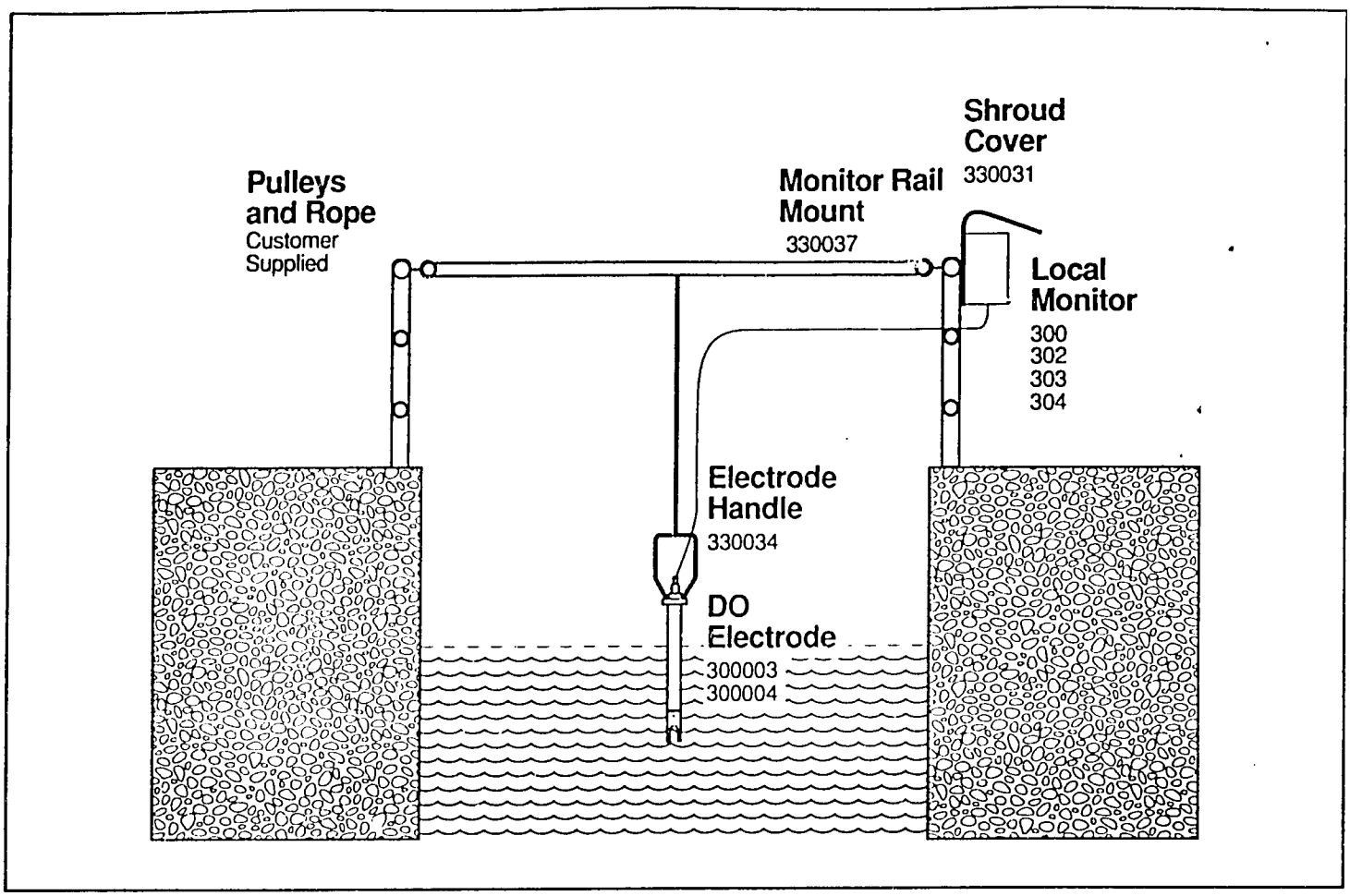

System 3: Dissolved Oxygen Tank Middle Oscillating Suspension System (Local Monitor)

Includes:

(QTY)

(1)❑ Model 300 (Cat. # 330001)
Digital display, manual calibration and barometric pressure correction.
or

❑ Model 302 (Cat. # 330201)
Same as Model 300 with alarm set points.
or

❑ Model 303 (Cat. # 330301)
Microprocessor, O_2 and temperature digital display, auto calibration and barometric pressure correction.
or

❑ Model 304 (Cat. # 330401)
Same as Model 303 with alarm set points.

(QTY)

(1)❑ Shroud Cover (Cat. # 330031)
(1)❑ Electrode with 21' Cable (Cat. # 300003)
or
(1)❑ Electrode with 49' Cable (Cat. # 300004)
(1)❑ Electrode Service Kit (Cat. # 300051)
(1)❑ Electrode Handle (Cat. # 330034)
(1)❑ Monitor Rail Mount (Cat. # 330037)
(2) Pulleys (Customer Supplied)
(1) Rope (Customer Supplied)

Please use boxes to check off items to be quoted.

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Process Monitoring Group
The Schrafft Center, 529 Main Street
Boston, MA 02129
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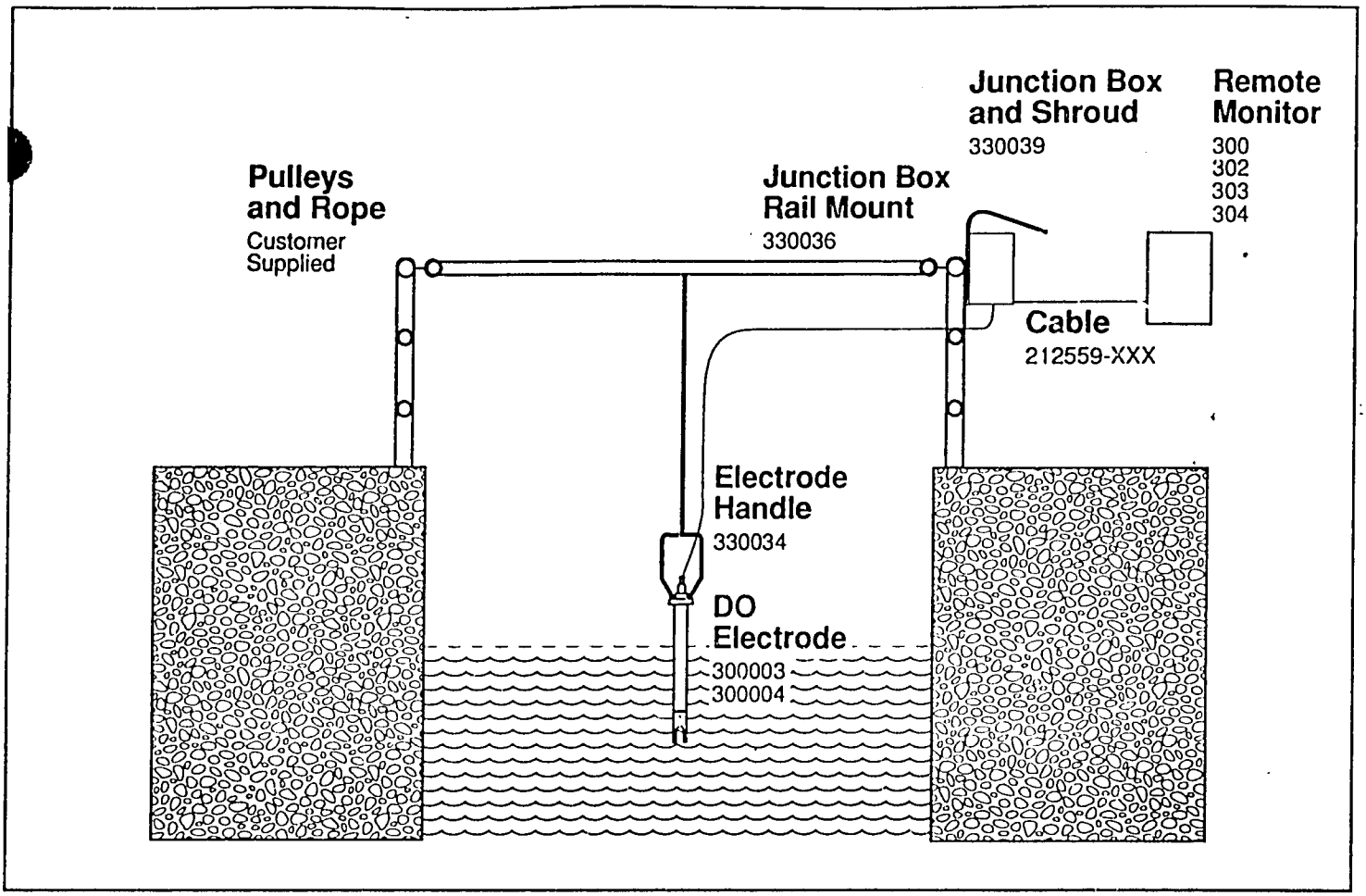

System 4: Dissolved Oxygen Tank Middle Oscillating Suspension System (Remote Monitor)

Includes:

(QTY)

(1)❑ Model 300 (Cat. # 330001)
Digital display, manual calibration and barometric pressure correction.
or
❑ Model 302 (Cat. # 330201)
Same as Model 300 with alarm set points.
or
❑ Model 303 (Cat. # 330301)
Microprocessor, O_2 and temperature digital display, auto calibration and barometric pressure correction.
or
❑ Model 304 (Cat. # 330401)
Same as Model 303 with alarm set points.

(QTY)

(1)❑ Junction Box and Shroud (Cat. # 330039)
(1)❑ Junction Box Rail Mount (Cat. # 330036)
(1)❑ Electrode with 21' Cable (Cat. # 300003)
or
(1)❑ Electrode with 49' Cable (Cat. # 300004)
(1)❑ Electrode Service Kit (Cat. # 300051)
(1)❑ Electrode Handle (Cat. # 330034)
(2) Pulleys (Customer Supplied)
(1) Rope (Customer Supplied)
(1)❑ Cable 10' (Cat. # 212559-010)
or
❑ Cable 25' (Cat. # 212559-025)
or
❑ Cable 50' (Cat. # 212559-050)
or
❑ Cable 100' (Cat. # 212559-100)

All cables include watertight plugs.
Please use boxes to check off items to be quoted.

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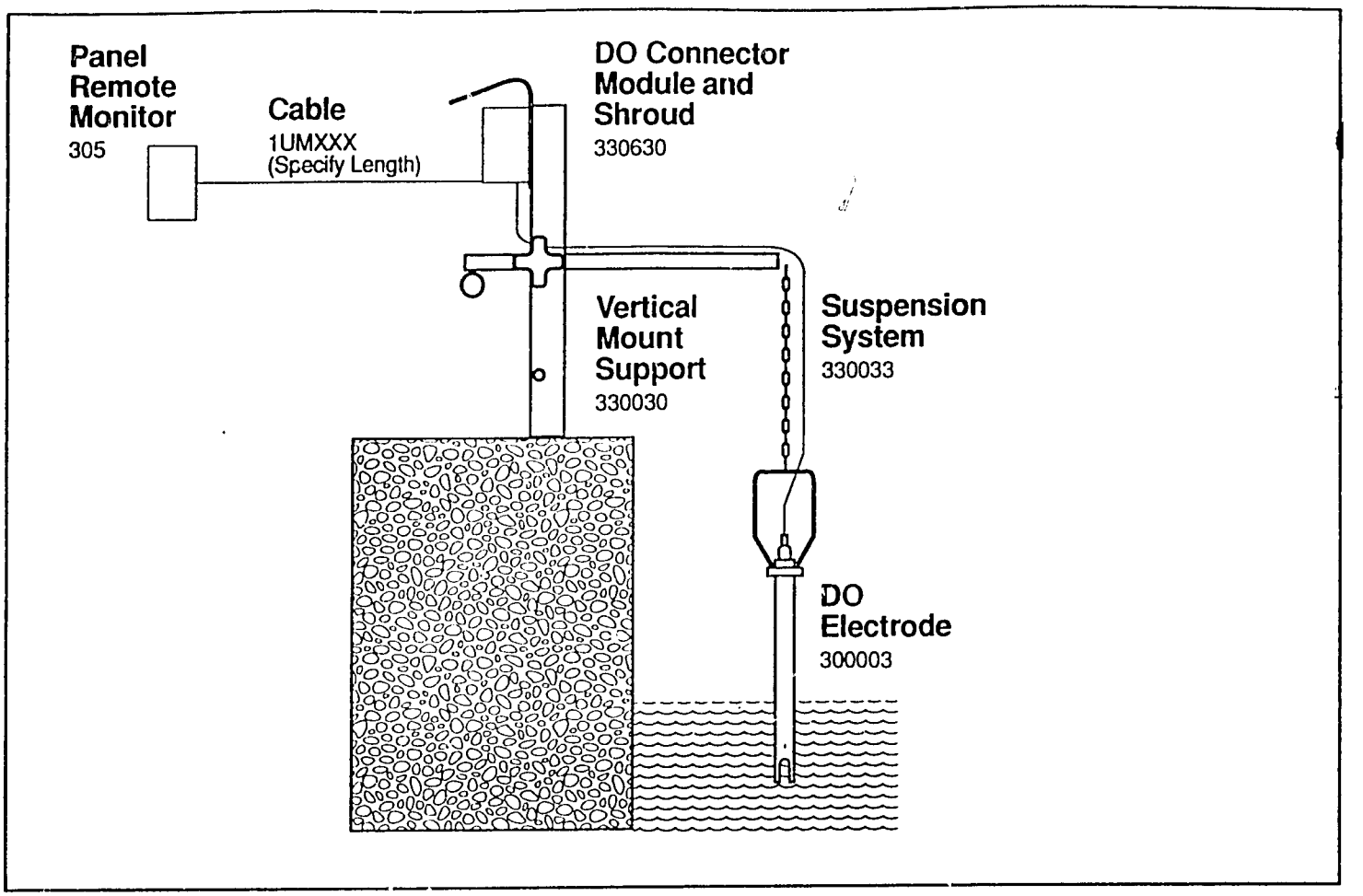

System 5: Dissolved Oxygen Tank Side Oscillating Suspension System (Panel Mount Remote Monitor)

Includes:

(QTY)
(1)☐ Model 305 (Cat. # 330500)
Digital display, manual calibration, manual barometric pressure correction, for panel mounting (24 VAC required)
(1)☐ DO Connector Module and Shroud Cover (Cat. # 330630)
(1)☐ Electrode with 21' Cable (Cat. # 300003)
(1)☐ Electrode Service Kit (Cat. # 300051)
(1)☐ Vertical Mount Support (Cat. # 330030)

(QTY)
(1)☐ Electrode Suspension System (Cat.# 330033)
(1)☐ Cable (1UMXXX) stripped and tinned on both ends. Specify length up to 3000' _____
Optional
(1)☐ Power Supply, 24V (Cat. # 212155-001)

Please use boxes to check off items to be quoted.

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Process Monitoring Group
The Schrafft Center, 529 Main Street
Boston, MA 02129
Tel: 1-800-225-1480 Fax: 1-617-242-4195

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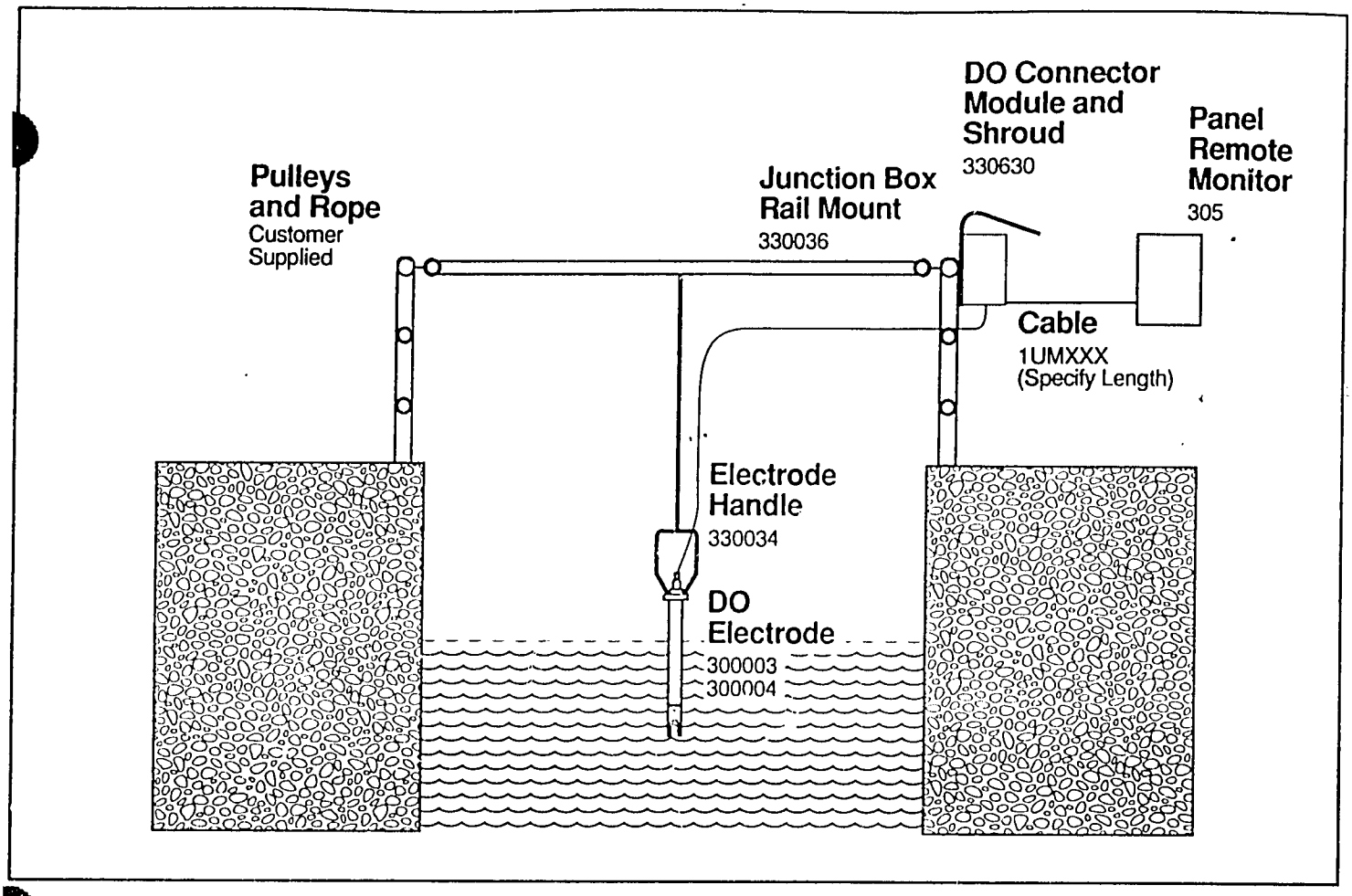
35



System 6: Dissolved Oxygen Tank Middle Oscillating Suspension System (Panel Mount Remote Monitor)

Includes:

(QTY)
- (1)☐ Model 305 (Cat. # 330500) Digital display, manual calibration, manual barometric pressure correction, for panel mounting (24 VAC required).
- (1)☐ DO Connector Module and Shroud Cover (Cat. # 330630)
- (1)☐ Electrode with 21' Cable (Cat. # 300003)
  or
- (1)☐ Electrode with 49' Cable (Cat. # 300004)
- (1)☐ Electrode Service Kit (Cat. # 300051)
- (1)☐ Electrode Handle (Cat. # 330034)

(QTY)
- (1)☐ Junction Box Rail Mount (Cat. # 330036)
- (2) Pulleys (Customer Supplied)
- (1) Rope (Customer Supplied)
- (1)☐ Cable (1UMXXX) stripped and tinned on both ends. Specify length up to 3000'_____ Optional
- (1)☐ Power Supply, 24V (Cat. # 212155-001)

Please use boxes to check off items to be quoted.

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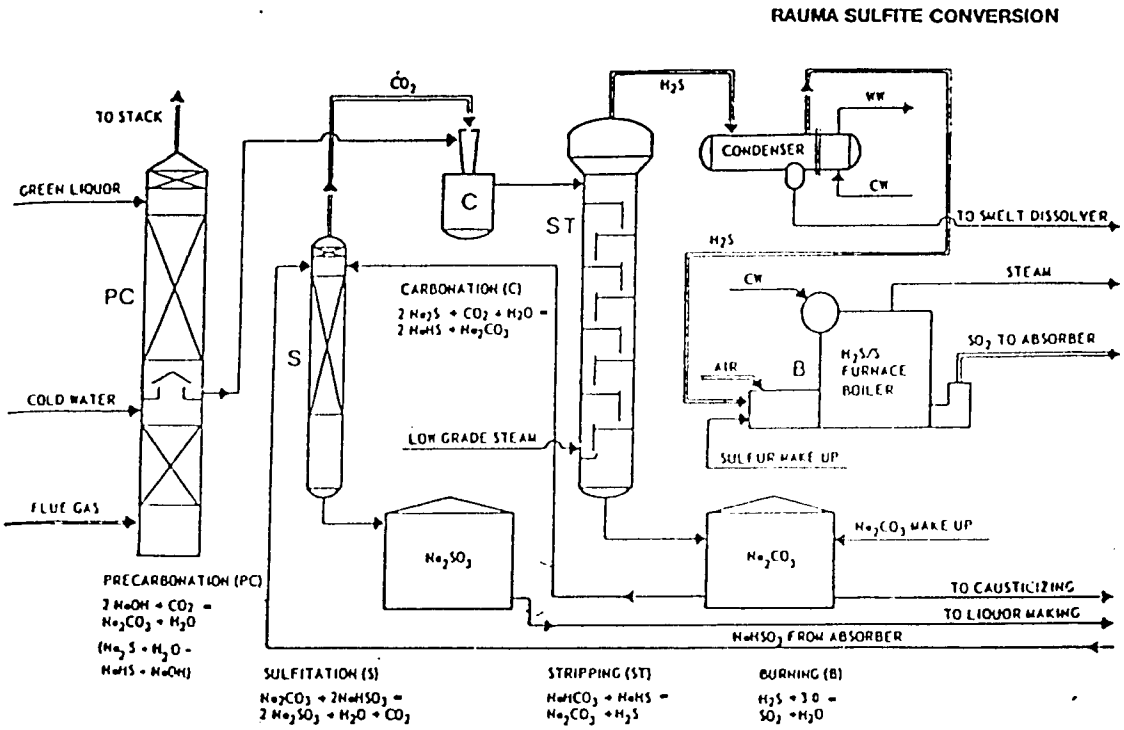
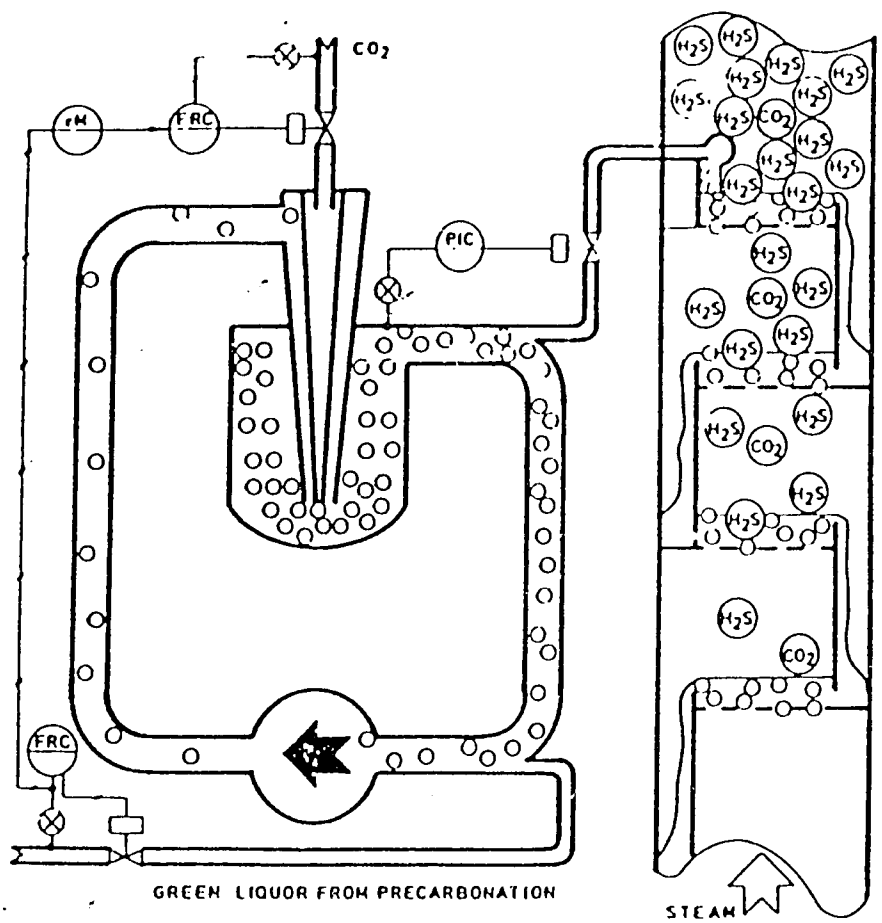
APPENDIX E - 2

SCHEMATIC OF RAUMA REPOLA SULFITE CONVERSION SYSTEM FROM GREEN LIQUOR



. Rauma sulfite conversion system from green liquor.



. Pressure carbonation of precarbonated green liquor and H_2S stripping at reduced pressure (Rauma Repola Oy).

Air Pollution: Controlled Operation of a NSSC Recovery Furnace

S. F. GALEANO, D. C. KAHN, and R. A. MACK

Abstract: Gaseous sulfur emissions from a kraft recovery furnace used in a neutral sulfite semichemical (NSSC) recovery system can be minimized by changes in operating variables. It is possible to obtain close to zero emission of total reduced sulfur by using proper distribution and quantities of primary and secondary airflows. Thermodynamics of the combustion and a scale of turbulence permit estimating those quantities. The sodium-to-sulfur weight ratio of the liquor fed to the furnace (in the 2–3 units range), is inversely proportional to the amount of sulfur dioxide released from the furnace. Adequate recording instrumentation in the process streams is essential in achieving the desired results. New recovery furnaces for NSSC processes can be expected to achieve the same degree of pollution control as new ones used in the kraft process.

Keywords: Air pollution · Recovery furnaces · Spent liquors · Neutral sulfite pulping · Recovering · Combustion · Process control

THE complexity of the different steps involved in the combustion of spent liquors makes evident the need for a careful investigation of the characteristics of the liquor considered. This is the case when using a kraft furnace for a neutral sulfite semichemical (NSSC) recovery system.

In comparing the spent liquors from these two pulping processes, we will use representative figures from kraft pulping on softwoods and NSSC pulping on hardwoods as it is most frequently practiced in the industry today. Table I is a summary of the major characteristics of these liquors. The first differentiation between the processes lies in the pulp yield. Consequently, the quantity and quality of organic and inorganic dissolved substances in the spent liquors vary, as indicated by the lower proportion of carbon in the NSSC spent liquor as shown by Annergren *et al.* (*1*).

The air requirements are naturally different when these processes are compared in terms of combustion. Loading capacities of the furnaces in tons of airdry pulp per day will vary because of the differences in black liquor solids and pulp yields. In pulp tonnage terms this means that a kraft furnace could handle a NSSC operation four to five times larger than its originally rated capacity.

However, this is not the whole picture. The heat generation capacity of the liquors is different, mainly because of the difference in lignin content, with the heat of combustion values of NSSC liquor solids about 75–80% of those of kraft liquor solids. This has been corroborated in our studies by heat value determinations and heat balances which include the additional amount of fuel oil necessary to bring up steam production to kraft rated levels.

CASE HISTORY

Our NSSC pulp mill in Tomahawk, Wis., uses a 150-ton capacity B&W kraft furnace in the recovery system. This system is closed with the Institute of Paper Chemistry (IPC) sulfitation system which prepares the green liquor for cooking.

Source emissions surveys in 1967 indicated a need for reducing sulfurous compounds emissions from the whole recovery operation. The first step taken in that direction was the elimination of the direct contact evaporator. In dealing with the emissions of sulfur compounds from the operation of the recovery furnace itself, it was decided that previous to any costly and cumbersome control scheme, an attempt to optimize the operating variables so as to reduce gaseous sulfur emissions was in order.

Experimental Design

The multi-variable situation prevailing in a recovery furnace poses a problem in any experimental design. However, by holding several of the independent variables constant it was possible to concentrate on the amount, the distribution, and the degree of turbulence of the air fed to the furnace.

In establishing levels for the variables, we checked for control and feasibility. In this fashion, we guaranteed the possibility of going back to a given value at any moment, and that the particular value was not objectionable in maintaining different operating conditions. We exerted good control in keeping constant the following: black liquor solids content (62%), temperature of the black liquor at the nozzle (215°F), temperature in the bed (around 2100°F), and amount of fuel oil added. No changes in nozzle type, firing pattern, etc., were introduced during the months of investigation. Smelt bed levels in the furnace were kept within established operating levels. Departure from this range created abnormal emissions of sulfide and/or sulfur oxides.

Equipment Used

Proper instrumentation and control are necessary. Black liquor solids were measured with an AccuRay analyzer. Air distribution and rates were obtained by a Bailey flow control system, calibrated on site. Pressure gages, level indicators, and weir measurements indicated rates of spent liquor and fuel oil. A Leeds & Northrup pyrometer was used for temperature measurements in the furnace. A Barton titrator was also used at the furnace outlet with continuous correction and calibration by wet analysis methods.

Requisites to Be Satisfied

The operation of a pollution controlled furnace must be a compromise between different and sometimes contradictory requisites. They are as follows:

1. Acceptable combustion efficiency
2. Chemical recovery as Na_2S and Na_2CO_3

Table I. Characteristics of Black Liquor Solids

Characteristic	Pulping process: NSSC	Pulping process: Kraft
Elemental analysis, %		
C	33	42
H	4.8	4
O	40	32
Na	14.2	18
S	6.4	4
Lignin, %, wood basis	1	25
Cellulose, %, wood basis	0	4
Hemicellulose, %, wood basis	18	19
Extractives, %, wood basis	1	2
Heat Value Btu/lb solids	5500	6600

S. F. GALEANO, Project Manager—New Systems Development, Technical Center, D. C. KAHN, Pulp Mill Superintendent, Tomahawk, Wis., Mill, and R. A. MACK, Project Engineer, Technical Center, Owens-Illinois, Inc., Forest Products Division, 1700 N. Westwood Ave., Toledo, Ohio 43601.

3. Minimization of Na_2SO_4 formation
4. Low alkali dust load
5. Elimination of sulfide emissions
6. Low SO_2 emission
7. Control of CO in flue gas
8. Control of nitrogen oxides

Solution

The complex processes taking place during combustion could be simplified into a system of reactions of inorganic substances. The two existing phases in the lower zone, gas and solid, can be described by thermodynamics postulates. The reactions and the values of the equilibrium constants are given in several publications (*2, 3*). The solution of simultaneous equations in order to obtain the partial pressures of each reacting substance at equilibrium is a rather tedious problem, but it is unnecessary for the approach taken here.

Logarithmic Equilibrium Diagram

The logarithmic equilibrium diagram was a concept introduced by Delahay (*4*) and Sillen (*5*) in studies of ionic equilibria and oxidation-reduction potentials. Sillen and Anderson (*6*) and Bauer and Dorland (*7*) have used equilibrium diagrams to describe the thermodynamics of the combustion process of calcium-, magnesium-, and sodium-base pulping systems. Two characteristics of these diagrams are quite helpful here. First, the configuration and slopes of different equilibrium curves remain the same for small changes in values of the components. A change in concentration will displace the diagram vertically but inferences about relationships, etc., will be valid. Only changes in temperature will cause appreciable changes in diagram configuration. Second, the ratio of the different oxidation states of a certain compound can be graphically established.

Mapping the Zone of Compromise in the Equilibrium Diagram for Primary Air

Figure 1 is an equilibrium diagram for a sodium-base pulping system based on the following assumptions:

$$pCO + pCO_2 = 0.15 \text{ atm}$$

$$pH_2 + pH_2O = 0.10 \text{ atm}$$

$$pH_2S + pSO_2 + pSO_3 + pS_2 \leq 0.01 \text{ atm}$$

Sodium is present in sufficient excess over sulfur to fix all sulfur to sodium and to obtain a Na_2CO_3 residue. These assumptions are valid in the lower primary zone where the partial pressure of water vapor does not include evaporated water.

Since our modification was to be achieved through air control, the partial pressure of oxygen was taken as abscissa and the partial pressure of the remaining compounds as ordinates, all in negative logarithms.

We then proceeded to narrow down the diagram according to our requisites, in the following fashion:

1. We disregard any area to the right of the point delimiting Na_2S and Na_2SO_4 formation (log pO_2 = −10.007), thus avoiding Na_2SO_4 formation.
2. The requisite of an acceptable good combustion is fulfilled by staying away from very low oxygen partial pressures. In this fashion, we disregard the area to the left of the point at which solid carbon will appear (log pO_2 = −19.29).
3. Decomposition of Na_2CO_3 is avoided by staying above the horizontal line at log pCO_2 = −6.453.
4. Alkali losses are reduced in quantity upon cooling and recombination with the gases in the upper zone of the furnace. Nevertheless, we must keep them as low as possible. A compromise point is logically the intersection of the Na_2 and H_2S curves. This will give the new to-the-left boundary.
5. We can further narrow down our area of compromise. Since minimum H_2S emission should take place, any area to the left of the point where the H_2S and SO_2 curves intercept will be acceptable. This point will be our new to-the-right boundary.

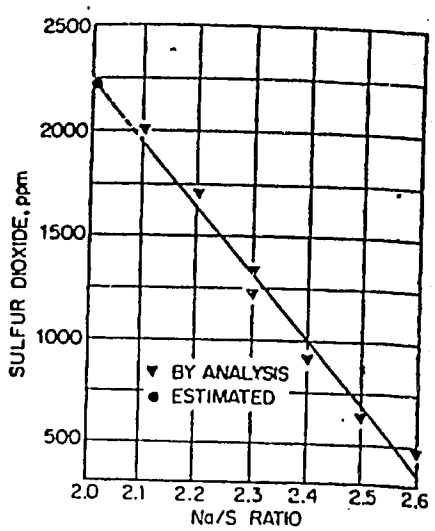


Fig. 1. Logarithmic equilibrium diagram for sodium-base liquor.

The new zone of compromise is thus the gray rectangle in Fig. 1. Within this zone, the left-hand side offers better fulfillment of most of the requisites, say lower H_2S and sodium partial pressures and less possibility of Na_2SO_4 formation.

We selected a midpoint in which we will have approximately:

58% of C as CO

42% of C as CO_2

58% of H_2 as H_2O

42% of H_2 as H_2

Primary Air

The amount of primary air was estimated in such a way as to satisfy the previously mentioned ratios according to the elemental analysis of the spent liquor. We also satisfied the Na_2CO_3 requirements of oxygen and kept in mind subtracting the oxygen content of the black liquor solids.

When considering the combustion of the auxiliary fuel oil, we decided to supply enough air to permit its combustion to CO_2 and H_2O. This will help for any dissociation of Na_2CO_3 and also will facilitate the oxidation to SO_2 of the remaining H_2S in the upper zone. The location of the fuel oil guns discharging right at the upper limit of the primary zone was another factor in consideration.

Table II indicates, at different operating conditions, the final values for primary air that were used to obtain zero sulfide emission in the flue gases. Also shown are the values from the prediction method already outlined. It is to be noticed how well they agreed. It is possible that some additional turbulence was required at the very low loading levels.

Table II. Theoretical and Actual Amounts of Primary Air for Zero Sulfide Emission

Loading level of furnace		Amount of air	
Solids, lb/hr	Nozzle pressure, psig	Prediction method	Actual[a]
18,600	65	61,000	63,000
17,000	55	54,000	54,000
15,600	45	48,500	49,000
11,988	35	42,000	45,500
8,800	25	36,000	43,500

[a] Under field conditions of zero TRS emission.

Table III. Stoichiometric and Effective Secondary Air

Loading level of furnace		Secondary air, lb/hr		
Solids, lb/hr	Nozzle pressure, psig	Stoichiometric	Effective[a]	Ratio E/S, F[b]
18,600	65	53,000	53,000	1.0
17,000	55	48,000	51,000	1.05
15,600	45	38,600	48,000	1.17
11,988	35	28,000	44,500	1.55
8,800	25	16,000	43,500	2.6

[a] For zero TRS emission.
[b] $F = 0.90 + 0.0955\,(P/65)^{-2.417}$.

Secondary Air and Turbulence

The amount of secondary air can be calculated by subtraction of the primary air from the total estimated requirements. Total air requirements were ascertained in the way indicated in standard texts. Air requirements in these calculations are minimums.

Additional air must be supplied usually as a percentage of the theoretical air. In our studies we were able to eliminate sulfide emission through the above procedure only at the highest loading level. It was apparent that at lower levels improper turbulence in the secondary zone impeded proper oxidation. Previous work on a kraft furnace (*8*) indicated that higher turbulence is required in the secondary air region. Unfortunately, it was a trial-and-error approach without indication of a turbulence parameter and for a fixed loading condition. For our different operating levels it would have been an extremely difficult trial-and-error approach, especially on a furnace in commercial production.

Since the air ports could not be modified, we concluded that the necessary degree of turbulence could be achieved by increasing the amount of secondary air above stoichiometric requirements. Table III indicates the calculated and actual amounts of secondary air used, and their ratio.

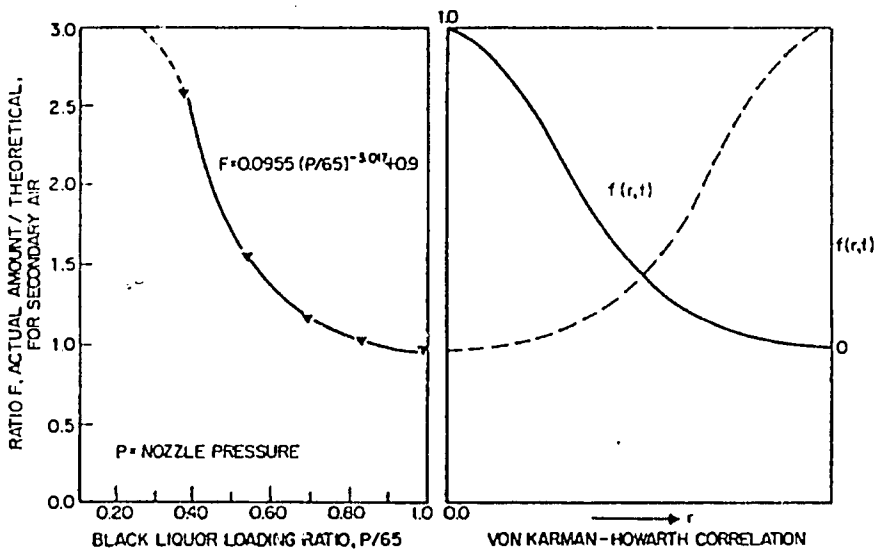


Fig. 2. Analogy for the scale of turbulence in secondary zone.

Scale of Turbulence

The correct solution for the optimum degree of turbulence needed in the secondary zone should include a scale of turbulence. The scale of turbulence will give, for each operating condition, the necessary amount and velocity of air. This can be thought of as an analogy to the von-Karman–Howarth equation (*9*) for the second-order correlation function $f(r, t)$. If r is the distance between two points, a correlation between the fluctuations at these two points will give a measure of turbulence. Another analo-

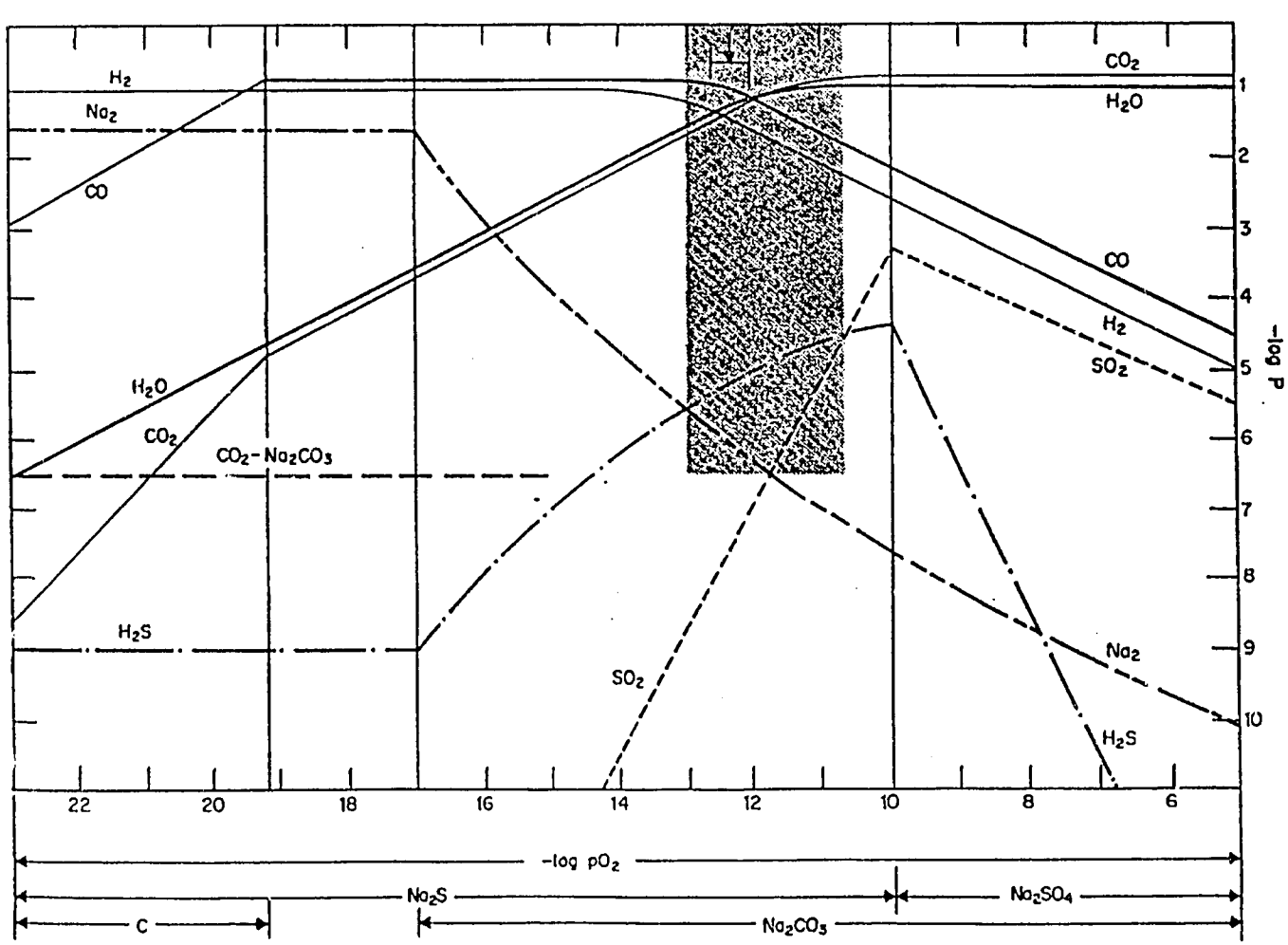


Fig. 3. Sulfur dioxide reduction with increasing Na/S ratio.

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gous element could be introduced if we consider the secondary ports system as a grid or mesh producing the turbulence. The decay of the intensity of turbulence is also expressed by the function $f(r, t)$.

For our fixed geometric dimensions in the furnace, a decrease in the loading will bring about a decrease in the distance, r, and time, t, after the grid, and consequently, a decay in turbulence. For lower loadings to the furnace it would be necessary to increase turbulence in the same fashion it decays, i.e., we need to trace back the curve which gives $f(r, t)$. Figure 2 indicates the high loading point (1,1) and the reverse curve (broken line). Point (0.4,2.5) was determined by proportioning and trial-and-error. With these two points, an operating equation was developed and estimations for each operating level were made.

Reduction of Sulfur Dioxide

There is a relationship between the Na/S ratio in the liquor and the emission of sulfur dioxide. When TRS emissions are reduced, the Na/S ratio decreases and sulfidity increases. Consequently, less alkali is available for recombination with the SO_2 in the secondary zone and thus SO_2 emission increases. Figure 3 gives the experimental data showing the relationship between Na/S ratio and SO_2 emissions. Clement *et al.* (*10*) have published similar data for a kraft operation. There may be a practical limit to the increase in the Na/S ratio. Adequate turbulence and cooling of the gases will promote efficient recombination and low alkali losses. There is need of about a 1000°F drop in temperature for best recombination results, but it should be rapid to avoid formation of other sulfur compounds. Cool tertiary air probably would help. The use of higher alkali loadings was considered and disregarded because of complications in exerting control. Also the formation of nitrogen oxides was an important factor under consideration.

Control of Carbon Monoxide and Nitrogen Oxides

As indicated earlier, the reducing conditions in the primary zone will lead to the formation of carbon monoxide which will be oxidized to carbon dioxide in the secondary zone. The temperature level in the secondary zone precludes dissociation of the dioxide to monoxide. Since the cooling rate is low in this reaction, no freezing of the equilibrium equation $CO + O \rightarrow CO_2$ should occur.

Two-stage combustion is one of the methods to reduce the formation of nitrogen oxides by at least 50%. This is the fashion in which the furnace is operated to obtain proper inorganic chemical recovery. Keeping the temperature relatively low in this process (2100°F) also aids in keeping the nitrogen oxides at a minimum. The endothermic reaction

$$N_2 + O_2 \rightleftarrows 2NO$$

with an equilibrium constant

$$\ln K = \frac{-43{,}200}{RT + 2.5}$$

will yield more nitric oxide as the temperature increases. Preliminary samples taken for analysis of nitrogen oxides indicated values generally in the 10 ppm range and no higher than 50 ppm by volume.

CONCLUSIONS

1. It was possible to reduce TRS emissions to zero by modifying the operation of our furnace. The use of fundamental principles of thermodynamics and full knowledge of liquor characteristics were necessary.
2. Proper instrumentation and control is required for the operation of the furnace. Continuous monitoring of flows and characteristics of the liquid and gaseous inputs to the furnace is required. Proper firing to avoid wall buildups which upset the bed upon falling is also needed.
3. Proper turbulence in the secondary zone is an essential factor.
4. A proper Na/S weight ratio must exist in the liquor for a desired level of SO_2 emission. This level will vary according to the recovery scheme. This approach seems to be the most straightforward to correct a given situation.
5. The two-stage type of combustion, as presently used by major recovery furnace manufacturers, seems adequate for an air pollution controlled furnace since its design can satisfy the thermodynamics and turbulence requisites.
6. New recovery furnaces for NSSC processes should be able to operate as efficiently as new units in the kraft process. The NSSC liquors can be concentrated in indirect contact evaporators.

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Presented at the Engineering Conference of the Technical Association of the Pulp and Paper Industry, held in Denver, Colo., Oct. 25–29, 1970.

APPENDIX E - 4

FACTORS AFFECTING SOME AIR POLLUTION PARAMETERS OF WOOD WASTE POWER BOILERS

In 1998, JCP's boiler K5 will not be in compliance with the air emission regulations when burning wood waste judging by the performance tests conducted on 27 and 28 of July 1994:

PARAMETER	1994 TEST RESULT - AVERAGE VALUE	1998 LIMIT
Particulates	1049	100
CO	4098	250
Organic Carbon (VOC)	373	50

The data indicate that the combustion process is not complete. Also, during the visit, the stack gas leaving the chimney was frequently black. This observation suggests the presence of small carbon particles which originate from wood. It follows that combustion needs to be improved not only to meet the future emission limits but also to utilize the wood waste more efficiently by generating more steam from a given dry weight of wood.

Time, temperature and turbulence drive the combustion process. The wood particle must absorb heat to elevate its temperature to the ignition point. Air, which supplies oxygen in the combustion process, must surround the wood and char particles. Insufficient availability of oxygen limits the rate of combustion. In grate burning boilers, the amount of wood that can be successfully burned on a given grate is usually limited. The limit is expressed as heat release per unit area. Grate or plan heat release is the product of dry mass rate of grate fuel and the heat content of the dry fuel divided by the grate area. The range varies between 2500 to 3800 kg $J/m^2/s$ depending on the grate and manufacturer's recommendations. At higher dry mass rates, combustion becomes incomplete.

Approximately 80 to 95% of the total ash residue produced in a wood waste burning boiler equipped with a grate is in the form of gas borne particles (fly ash). The remainder of the total ash residue stays in the boiler and leaves as bottom ash. The fly ash consists of wood inorganics, sand contaminants and unburned char.

Some important combustion parameters affect the degree of burnout of the entrained char and thereby the weight concentration of the particulates. The parameters include heat release rates which directly impact on furnace temperature and retention time. Char burnout is also governed by aerodynamic factors such as:

- furnace shape;
- overfire jet geometry;
- fuel size distribution;
- char reinjection;
- ratio of undergrate to overgrate air;
- combination firing.

Char reinjection would especially have a large effect on particulate emissions because the reinjected char reduces the average particle size and increase dust loading to the emission control device.

Amongst the emissions associated with wood waste burning, CO is usually the most variable. . At normal excess air levels fuel heating value as fired and fuel distribution are the most important parameters that affect CO emission. The CO concentration in stack gas increases with:

- high excess air which causes **combustion zone cooling;**
- low excess air (insufficient oxygen);
- high fuel moisture content;
- reduced load.

Organic carbon (VOC) originates from wood pyrolysis followed by incomplete combustion before the flue gas leaves the boiler. Aldehydes and benzenes are the predominant hydrocarbons in the stack gas. For the JCP 1994 test results, a linear relationship exists between CO and VOC (Figure 1).

Control technologies have received much technical attention during the last few years. Several methods exist for reducing the particulate emissions from boilers. They include:

- supply of dryer fuel to achieve more complete combustion (dryer fuel can conveniently be prepared with a waste dryer utilizing boiler stack gas);
- elimination of fly ash reinjection;
- upgrading of the overfire air system of the boiler to improve penetration of the pyrolysis gas with air and gas mixing;

- replacement of the lower furnace with an improved grate or fluid bed combuster;
- addition of an electrostatic precipitator.

CO emissions are minimized by:

- good control of homogeneous fuel feed rate;
- maintenance of combustion temperature;
- adequate excess air (based on continuous oxygen and CO measurements);
- good gas mixing.

Optimum levels of excess air, the lowest possible fuel moisture, maintenance of boiler load and controlled rates of change of boiler load have all been demonstrated to reduce the CO concentration of the stack gas. Too low excess air has to be avoided due to increased risk of higher CO concentrations and unburned organic compounds.

Organic carbon content of the stack gas is controlled in a similar way as CO emissions. Emissions of volatile organic compounds are minimized by:

- ensuring good mixing in the upper boiler volume;
- control of boiler temperature;
- excess air.

From the above, it follows that reduction of the emission loads in the stack gas from JCP's boiler K5 to the low limit of 1998 would require improvements of combustion, perhaps by installing a new combustion air system and burning of dryer fuel.

Boiler suppliers, e.g. ABB Combustion, have been using computational fluid dynamics software to model the operation of boilers and optimize the performance of their air systems. For example, reduction of particulate emissions has been achieved by lowering the air velocity in the bottom of the boiler. New designs have been developed to distribute oxygen more efficiently throughout the boiler, especially in fuel rich areas which are usually starved for oxygen in older boilers. This improvement also reduces air velocity in the bottom of the boiler thereby decreasing stack emissions.

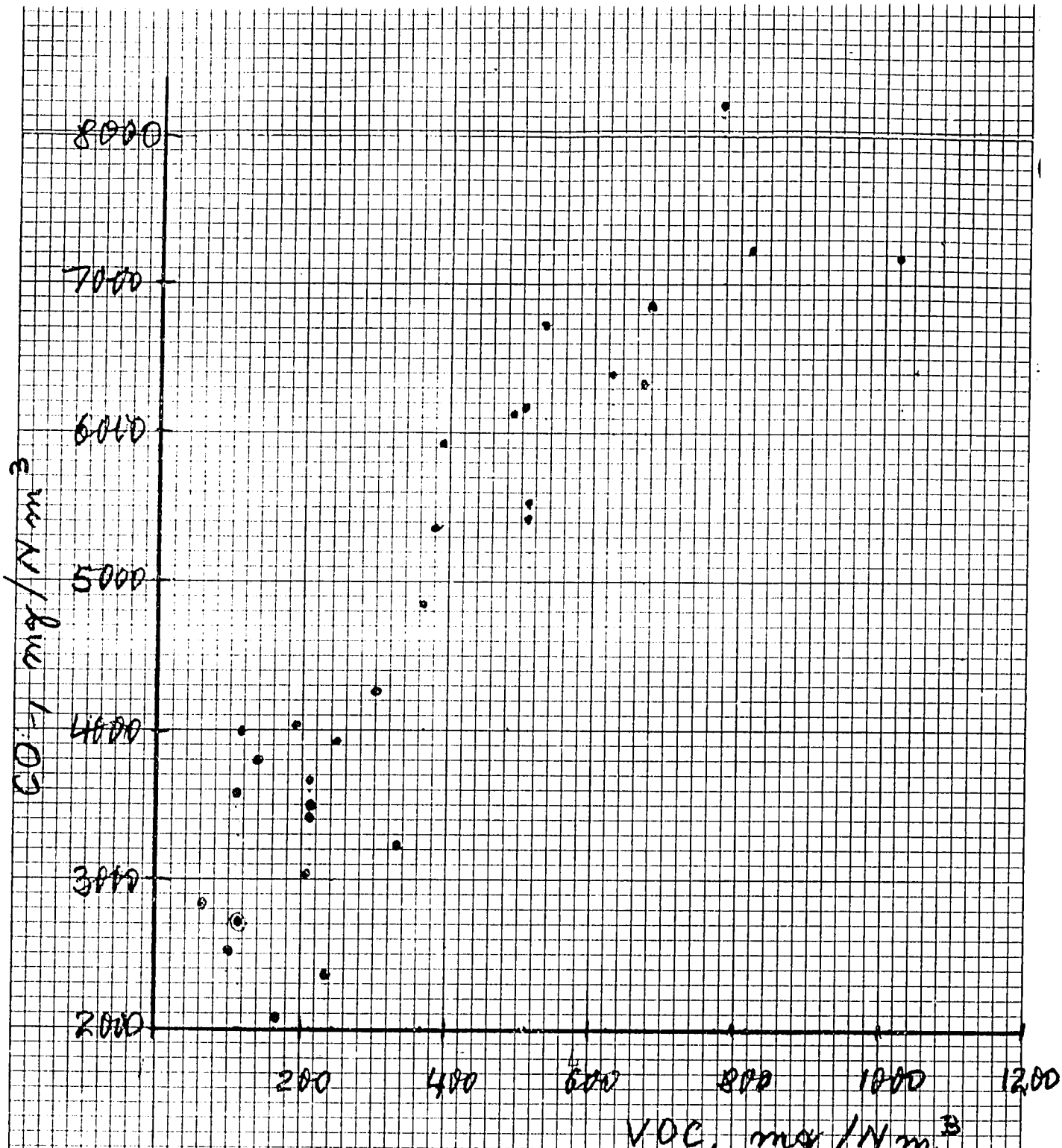

Fig. 1: CO — VOC Relationship of Stack Gas from Boiler K 5 With Wood Waste as Fuel — 27 and 28 July 1994

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APPENDIX F - BIOGRAPHY

HANS E. WÖRSTER

EDUCATION

- MSc. (Diplom Chemiker) and Dr. rer. nat. in pulp and paper chemistry and technology at the Technical University (Technische Hochschule) Darmstadt, Germany

- Doctoral thesis on semichemical pulping (NSSC) of hardwoods and sawmill residue including bleaching

INDUSTRIAL EXPERIENCE

1. 1959 - 1963:
   Columbia Cellulose, Prince Rupert, B.C. Canada
   Work Areas:

   - sulfite pulping and bleaching of dissolving pulps for cellulose acetate and viscose
   - wood evaluation and kraft pulping studies for green field bleached kraft market pulp mill at Castlegar, B.C. (part of Columbia Cellulose at that time) and mill start-up experience

2. 1963 - 1985:
   MacMillan Bloedel, Vancouver, BC, Canada
   Work Areas:

   - various projects related to kraft pulping, bleaching, chemical recovery and pollution abatement for the company's four kraft pulp mills
   - project development, design, engineering and technical leadership of a major modernization and expansion project of MacMillan Bloedel's linerboard and corrugating medium mill located at Pine Hill, Alabama, USA, including green liquor semichemical pulping, old corrugating container (OCC) waste recycling and stock preparation start-up experience
   - assessment of South American plantation softwoods for 1000 t/d bleached kraft market pulp mill - technical project leadership

3. 1985 - present:
   Fletcher Challenge Canada, Vancouver, BC, Canada
   Work Areas:
   - mechanical pulping and bleaching, e.g. TMP and CTMP process desing, and newsprint technology
   - recycling of waste paper for newsprint
   - pollution abatement including internal environmental performance auditing

- various kraft pulping, bleaching, recovery and quality projects
- studies on value added paper production
- technical support to pulp customers producing a wide variety of packing, printing, writing, hygienic, technical and specialty papers and using pulp in non-paper applications, e.g. fiber cement boards
- assessment of annual plants and imported chips as raw materials

OTHER ACTIVITIES

- Lectures at Chemical Engineering Department at University of British Columbia on pulp and paper technology (1973 to 1993) and at B.C. Institute of Technology

- Technical advisory board and committees of various technical conferences

- World Environment Center volunteer since 1990; nine missions for environmental performance and waste minimization audits to pulp and paper mills in Asia, Egypt and Eastern Europe

CURRENT POSITION

Technical Director, Pulp & Paper
Fletcher Challenge Canada, Vancouver, BC, Canada

PUBLICATIONS AND PATENTS

35 papers in various technical journals
10 patents on pulping technology

AWARDS

1980 MacMillan Bloedel's President Award for achievements at the Pine Hill mill
1986 TAPPI[1] Pulp Manufacturing Division Award and Johan Richter Price for technical contribution to the pulp industry
1989 TAPPI fellow for technical achievements in pulp and paper manufacturing technology
1992 First Outstanding Volunteer Award from the WEC (World Environment Center, New York) for environmental, industrial hygiene, safety and waste minimization audits of pulp and paepr mills in various countries

(1) Technical Association of the Pulp and Paper Industry - with the head office in Atlanta, Georgia, USA

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ADDENDUM TO
TRIP REPORT OF JULY 1995 ENTITLED

"ENVIRONMENTAL AND WASTE MINIMIZATION ASSESSMENT VISIT TO JUHOSLOVENSKE CELULOZKY A PAPIERNE"

STUROVO, SLOVAK REPUBLIC

By: Dr. Hans E. Wörster

WORLD ENVIRONMENT CENTER
419 PARK AVENUE SOUTH, SUITE 1800
NEW YORK, NEW YORK 10016

Addendum Date:
SEPTEMBER 1995

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I. INTRODUCTION

In June of 1995, Dr. Hans E. Wörster, pro bono specialist, Fletcher Challenge Canada Ltd., visited the Juhoslovenski Celulozky a Papierne A.S. - Papermill (JCP) located in the town of Sturovo in Southern Slovakia, on the Danube River. The objective of this visit was to conduct an environmental assessment of the JCP plant and identify opportunities for pollution reduction and waste minimization.

In July 1995, WEC issued Dr. Worster's trip report of his visit to JCP. After receiving additional information about JCP from the plant, Dr. Worster submitted the following addendum to his July report.

II. EXECUTIVE SUMMARY

This report is an addendum to the trip report entitled "Environmental and Waste Minimization Assessment to Juhoslovenske Celulozky A Papierne (JCP) Sturovo, Slovak Republic, June 26 to 30, 1995," prepared by H.E. Wörster, Technical Director Pulp & Paper, Fletcher Challenge Canada, in early July 1995.

Since the time period allowed for the visit was too short to collect sufficient detailed information on JCP's effluent treatment system, this information was sent to Dr. Wörster after his return to Canada by JCP's Manager of the Environmental Protection Department.

This report contains an analysis of the operation of JCP's existing activated sludge effluent treatment system, considerations toward expansion of the existing system to meet future discharge limits, and recommendations on the components of an expanded system.

The data confirm that removal of the biological oxygen demand (BOD_5) in the activated sludge system is low compared to similar systems operated elsewhere. JCP's biological treatment plan is underdesigned for the mill's effluent volume.

Calculations based on JCP's test data suggest the following:

- BOD_5 loading exceeds that of well performing similar systems;
- the ratio of BOD_5 load to the quantity of sludge containing the active microorganisms (which remove BOD_5) is at the high end or above that of well performing systems;
- the high ratio is at least partly caused by the poor settling sludge recycled from the secondary clarifiers.

A comprehensive monitoring program is recommended to better understand the reasons for the relatively poor performance of the system and to generate input data for upgrading and expanding it.

The limited information currently available suggests that, for meeting future stricter effluent discharge regulations, all mill effluent should be treated in an extended activated sludge system. Obviously, the system needs to be well designed and it would have to be operated efficiently on the basis of more extensive testing than conducted currently. Also, important components of the expanded system should include a spill collection basin, an efficient equalization basin, and automatic on-line test and control equipment.

In-plant steps such as improved NSSC pulp washing and spill containment in the chemical regeneration plant should be part of the overall strategy directed toward meeting future stricter effluent discharge limits.

II. CONCLUSIONS AND RECOMMENDATIONS

1. Exiting Activated Sludge System

JCP's test results of 1994 and the first half of 1995 indicate low BOD_5 removal efficiencies for the existing activated sludge effluent treatment system. The overall BOD_5 input of 1,273.6 tonnes to the activated sludge system and an output of 580.3 tonnes in 1994 indicate a removal efficiency of only 54.5%. Similarly, in the first six months of 1995, BOD_5 input and output were 756.7 and 241 tonnes respectively, giving a removal efficiency of only 68.2%. Efficiently operated activated sludge systems provide 85 to 95% BOD_5 removal efficiency. The question arises as to why the BOD_5 removal efficiency is so low at JCP.

Insufficient data is available to explain the low efficiency. Old test data indicated relatively low concentrations of dissolved oxygen (DO) in the activated sludge system itself. Since oxygen solubility decreases with increasing temperature, control of temperature may also be important and temperature measurements should be combined with DO testing. Effluent cooling ahead of the activated sludge systems is practiced in many mills to protect the microorganisms and increase oxygen solubility.

Also, performance details of the aerators are important. Supplier data on oxygen transfer (kg/d) and operating recommendations on preferred liquid depth and aerator blade immersion should be checked to ensure that sufficient oxygen is made available.

The so-called food to microorganism ratio (F/M), which is essentially the ratio of BOD_5 to the mixed liquor suspended solids (MLSS), has to be within a certain range for efficient BOD_5 removal. The MLSS originate from the recycle stream pumped from the secondary clarifiers for mixing with the untreated effluent immediately ahead of the activated sludge basin. Verbal information obtained during the visit to JCP from June 26 - 30, 1995, indicated approximately 4 to 6 grams of MLSS per liter of recycled effluent and a recycle ratio of 1.5.

Calculation of the major design operating parameters from JCP's average data gives the following results compared to extended aeration systems with 18 to 24 hours hydraulic retention time, which provide 75% to 90% BOD_5 removal efficiency.

TIME PERIOD	1994	JAN - JUNE 1995	GOOD SYSTEMS
MLSS, mg/l	3000	3000	3000 - 6000
F/M, kg BOD/kg MLSS	0.21	0.15	0.05 - 0.15
Volumetric Loading, kg BOD_5/m^3	0.86	0.45	0.16 - 0.40

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These data show that, at JCP, on the average the MLSS concentration in the activated sludge system was at the low end and the F/M was at the high end and above the range of systems that are performing well. Also, the volumetric BOD_5 loading was significantly above the common range in 1994 and slightly above it in the first half of 1995. In plant steps such as better NSSC pulp washing and spill collection in the chemical regeneration area would reduce the BOD5 loading. This reduction in BOD loading would also lower the F/M and thus should lead to higher BOD_5 reduction efficiencies.

Alternatively, an increase in the MLSS concentration would also result in lower F/M. However, this would require better settling, i.e. a lower settled volume index (SVi) of the MLSS in the recycle from the secondary clarifier. The high SVi of the recycle at JCP (150 to 200 ml/g compared to 80 ml/g for good settling) is probably mainly due to very high portion of filamentous bacteria in the sludge. Growth of filamentous bacteria is favored by:

- low dissolved oxygen concentration, especially in combination with high F/M;
- presence of readily degradable BOD_5 such as starch, e.g. from OCC waste;
- high sulfide concentration, i.e. from sodium sulfide containing spills and hydrogen sulfide contain condensate from the chemical regeneration system;
- nutrient deficiency;
- low pH.

From the above, it follows that more information is needed to understand the main reason for the relatively low BOD_5 reduction efficiency. To this end, a monitoring program around the activated sludge system is recommended. It includes some of the testing already being conducted. A list of the proposed monitoring program is given in Table 1.

TABLE 1

PROPOSED MONITORING FOR THE ACTIVATED SLUDGE PLANT

MONITORING/TESTING	FREQUENCY
Influent flow	1/day
Dissolved oxygen (DO)	2/day
Temperature	2/day
pH	1/day
Nutrient flow	1/day
Sludge volume index (SVI)	1/day

54

MLSS/MLVSS[1]	1/day
Secondary clarifier DO	2/day
Return activated sludge flow	1/day
Microscopic exam of MLSS	1/day
Oxygen uptake rate	2/week
Settling Velocity of MLSS	2/week
Waste activated sludge volume	1/day
1. MLSS/MLVSS - Mixed liquor suspended solids and volatile suspended solids	

Data established over a period of several weeks of representative mill operation should then provide the information required for upgrading of the existing activated sludge system.

At this time, every effort should be made to reduce spills in the NSSC pulping and regeneration area in order to reduce the volumetric BOD_5 loading to the activated sludge system. This reduction would result in a lower F/M, which in turn should increase the BOD5 removal efficiency and, obviously, also the BOD_5 content of the effluent discharged into the Danube River.

2. Considerations Towards Additional Biological Effluent Treatment Facilities

Calculations based on JCP's data of 1994 and the first half of 1995 indicate average volumetric BOD_5 loadings of 0.40 and 0.55 kg/m^3 of the total effluent respectively from <u>all</u> mill departments. To reach the BOD_5 limit of 50 mg/liter required by 1 January 2005, the BOD_5 removal efficiency would have to be 87.5% and 91% respectively on the average. This removal efficiency can be reached with well designed and well operated activated sludge systems. Nevertheless, it is expected that a significant reduction of the volumetric BOD_5 loading will be accomplished by improved NSSC pulp washing and spill collection in the chemical regeneration area. However, data are not yet available to calculate the impact of these in-plant steps on BOD_5 reduction.

At a MLSS concentration of 3000 mg/liter (e.g. at a recycle ratio of 1.5) in the activated sludge tank, the F/M would be 0.06 and 0.08 for the 1994 and the first half of 1995 untreated effluent flow rates and BOD loadings respectively. These F/Ms are well within the range of the extended aeration mode of activated sludge effluent treatment technology with hydraulic retention times of 18 to 24 hours in the aeration basin.

The above F/M data serve only as an example. Obviously, somewhat different results would be obtained with other MLSS concentrations in the activated sludge tank. Different M/F would

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easily be possible, e.g. with other recycle ratios than the 1.5 ratio assumed above. However, the general conclusion would probably be that extended aeration would be suitable.

Calculations based on JCP's indicate data average COD concentrations of 686 to 878 mg/l for the total effluent volume from all departments in 1994 and the first half of 1995 respectively. At 68% COD reduction, which can be accomplished in a well designed and well operated activated sludge system, the above COD loading should result in final effluent with approximately 220 to 280 mg/l. This COD concentration range would be close to and somewhat above the 250 mg./l limit that will be enforced on 1 January 2005. However, improvements in NSSC pulp washing and spill collection and spill recycle in the chemical regeneration plant should reduce the COD discharges significantly.

JCP's data made available to Dr. Wörster on total suspended solids contents of the untreated department effluents are incomplete in that no test results were provided for the effluent from Plant III. JCP's average test data for 1994 indicate 110 mg TSS/l and 1,798.3 tonnes/year for the effluent discharged into the Danube from the manufacturing facilities. These discharges are too high compared to the 1 January 2005 limits of 50 mg/l and 1,250 tonnes/year. The available numbers do not indicate how much of the TSS is fiber and other solid material and how much is biomass from the activated sludge system. Therefore, in the absence of this information, it can only be recommended that primary sedimentation and the SVi of sludge from the existing activated sludge system be improved and that a new/expanded biological treatment system be designed and operated in such a manner that well settling sludge is generated.

3. Components of an Efficient Activated Sludge System

The major components of an efficient activated sludge system regardless of its rate are:

- primary clarification of all mill department effluents containing fibrous and other solid materials;

- an equalization basin for mixing of all effluents. Twelve hour retention time is recommended to minimize variations in BOD_5, COD, pH and temperature, etc. caused by inconsistencies of the manufacturing processes. If the potential for odor release exits, e.g. due to the presence of sulfides, the basin should be covered and the air space under the cover should be vented through charcoal filters to eliminate odors and other objectionable gas emissions such as VOC;

- emergency and spill collection basin for storage and for metering high BOD_5/COD or toxic effluents (identified by high conductivity, very dark color or high turbidity) to the equalization basin at such a rate that the microorganisms of the activated sludge system are not affected adversely;

- pH control and nutrient addition to provide satisfactory conditions for the biological processes in the activated sludge basin;

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- temperature control to avoid high temperatures at which the microorganisms' efficiency would suffer; cooling towers or heat exchangers may be necessary depending on the maximum temperature and flow rate of individual mill department effluents;

- activated sludge (biological) basins with efficient properly positioned aerators

- secondary clarifiers for good settling of sludge from the biological treatment and pumps for feeding some of the settled sludge back to the inlet of the activated sludge system for control of the microorganism population and of the F/M;

- thickening of excess sludge from the secondary clarifiers with filters and presses before disposal of the sludge, e.g. in a landfill;

- automatic on-line test and control equipment, e.g. conductivity meters to identify high BOD_5 effluent from the NSSC pulp mill and the chemical regeneration area or from other areas of the mill.

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