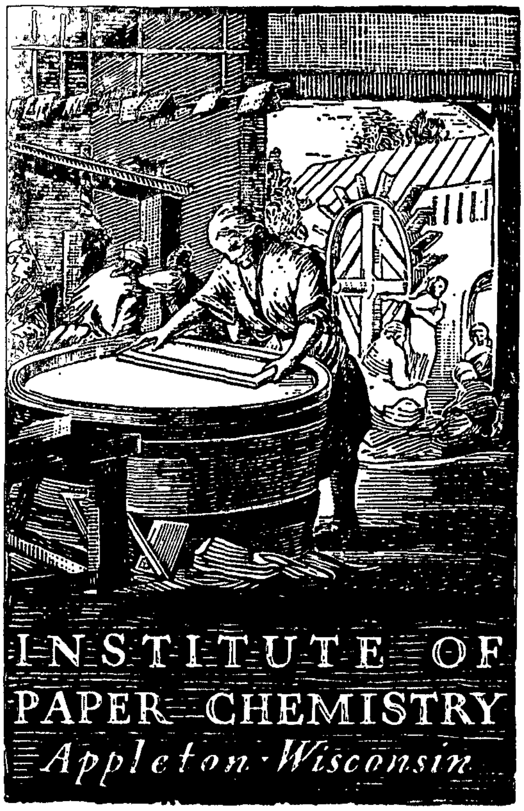

WATER RECYCLE SYSTEM SIMULATION

Project 3251

Report Two

Final Report

to

MEMBERS OF THE INSTITUTE OF PAPER CHEMISTRY

March 29, 1979

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

The simulator DYSCO (Dynamic Simulation on Control) was adapted from the petrochemical industry for use in the pulp and paper industry. This module-oriented simulator was used to simulate an integrated groundwood mill. The process, as simulated, contained some 150 process modules and 250 process streams.

The mill as currently operated was simulated. Analysis of the data indicates that some 90 hours are needed to go from one steady-state condition to another. Results were compared to mill data.

Mill water system closure was simulated by collecting all sewered effluents, screening them, and using the clear filtrate to replace fresh water flows. Simulation results indicate that dissolved solids will increase by about a factor of 10 over the current operating mode. No temperature rise predictions were made.

INTRODUCTION

Recycling of process water is common practice in the pulp and paper industry. Mill water system closure is often limited, however, by the lack of information on the resultant buildup of dissolved and suspended solids and increases in temperature. Stringent effluent guidelines from state and federal agencies will encourage more intensive process water reuse. Rising energy costs will dictate that low level heat be recovered whenever technically and economically feasible. Systems analysis and one of its primary tools, simulation, will be keys to finding effective and efficient recycling schemes.

The Institute has been involved in system simulation for some time. Report One of this project (1) described a simple dynamic simulation package (SIMPAK) for modeling mill water systems. This report is an extension of that work.

A review of the capabilities of SIMPAK and a comparison with projected simulation needs indicated that extensive work would be needed on SIMPAK to make it a useful tool. Rather than expend effort refining SIMPAK, we chose to select a simulation package from the petrochemical industry and modify it to the needs of the pulp and paper industry. After an extensive review, DYSCO (2) [Dynamic Simulation and Control] was chosen as the package that would best meet our needs.

DYSCO is a modular simulation package that allows the user to interactively control the simulation. Like most modular simulators, the process to be simulated is represented as a series of unit operations connected by pipes, or, more conventionally, streams. As currently written, the simulator can carry information about eight components in addition to the flow, temperature, pressure, density, and enthalpy. This capability allows the user to study up to eight different components, dissolved or suspended, in the process fluid. The number of components is also easily expanded. At the present time, it can simulate a process with 150 process units and 300 process streams.

The overall goal of this project was to model a mill water system. Primary emphasis was on tank holdups and water distribution. Emphasis was not focused on the chemical changes occurring during pulping and bleaching or the dynamics of sheet formation. This focus allowed simple models to be used, thus allowing us to develop the simulation techniques without being bogged down in the fine details of the kinetics of pulping and bleaching, physicochemical interactions, and the mechanics of sheet formation, or the intimate description of separations processes.

OBJECTIVES

Initially, Project 3251 was broken into four phases:

Phase I. Refine SIMPAK to increase computational efficiency.

Phase II. Develop the data base for a SIMPAK simulation of a selected board mill.

Phase III. Verify the SIMPAK simulation with data collected at the selected board mill.

Phase IV. Develop alternative system closure schemes using SIMPAK.

The results of Phases I and II were discussed in Report One (1). The remaining objectives of the project were modified when the decision was made to obtain and develop a new simulation package. With this decision, Phases III and IV were deleted and replaced by:

Phase III. Replace SIMPAK with DYSCO.

Phase IV. Test DYSCO with data from a mill and verify the results.

Phase V. Develop recycle alternatives utilizing DYSCO.

RESULTS AND DISCUSSION

Phase III involved adapting routines from SIMPAK for use in DYSCO and developing new models to allow a mill to be simulated. This is, naturally, an on-going process. Sufficient routines have been developed and tested to allow a stone groundwood mill to be simulated. The routines currently available in DYSCO are listed in Table I.

TABLE I

ROUTINES AVAILABLE IN DYSCO

DYSCO Routines	Type (Dynamic or Instantaneous)	Description
Mixer	D	Constant volume tank that mixes N incoming streams into one output stream
DYSSEP	I	A filterlike device that separates a stream into two streams with differing composition
DYSTRB	I	A pipe header that distributes an in-flowing stream unequally into N out-flowing streams
DYSMIX	I	A pipe-tee device that mixes N incoming streams into one outflowing stream
CONSIS	I	This filterlike device controls the consistency of one compound to a fixed level in the output stream
REGLTR	I	This device controls the mass flow of a given component to a specified level

In Table I, only the MIXER models a dynamic process. The remaining units model processes that are assumed to occur instantaneously. This is not a limitation of the DYSCO simulation package, but rather represents the routines needed to model the mill.

Earlier work on this and other projects have resulted in an extensive mill description for the stone groundwood mill of the St. Regis Paper Company at Sartell, Minnesota. These data were used to check the ability of DYSCO to simulate a mill process. The DYSCO schematic of the integrated mill is given in Fig. 1,* with a definition of the symbols given in Table II. This process flow sheet contains some 150 process modules and 250 streams. An experimental program was performed at the mill in which the pulp mill water systems were isolated from the rest of the mill. Sodium bromide was injected at a constant rate into the bull screen tank for seven hours and the buildup of bromide ion was followed at several points in the pulp mill. DYSCO was used to simulate this experiment. For reference, the pulp mill portion of Fig. 1 is shown in Fig. 2.

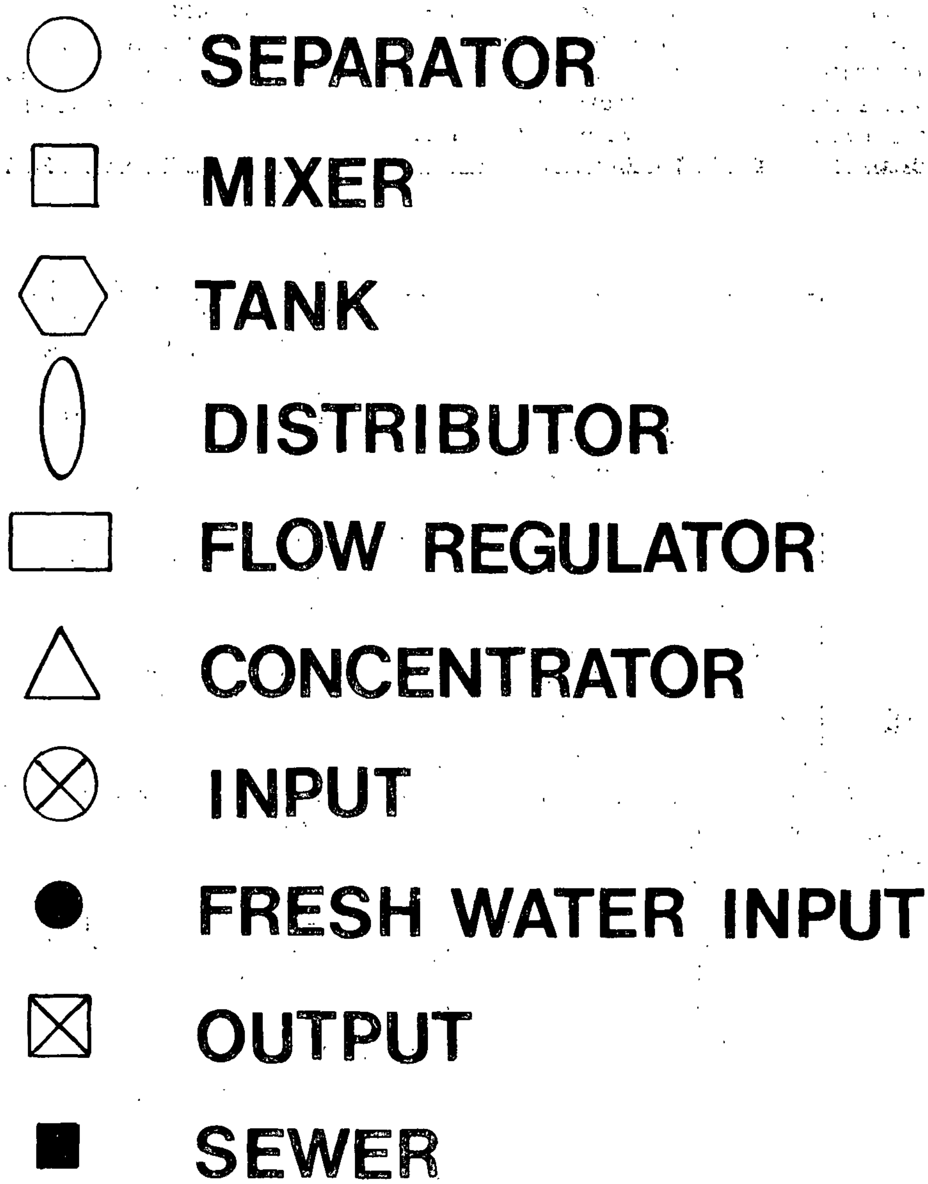
The results of this test are shown in Fig. 3 and 4 for two points in the mill. The simulated and experimental data agree quite well for the first half hour or so, and then start to diverge. The experimental and simulated results follow a relatively simple first-order response. The fluctuations in the experimental data may be the result of many factors. For example, at two points in the experiment, water from the paper mill was admitted to the pulp mill. No measurement was made of these flows, but they will cause fluctuations in the tracer concentration. The injection of the tracer also was not smooth, with pulses occurring each time a drum was exhausted and a new one started. The simulation run assumed all other flows to be constant.

An attempt was made to vary the process parameters in the simulation to shift the simulated curve to coincide with the experimental data. Such experiments

*Figure 1 is a foldout blueprint of the mill contained in a pocket inside the back cover.

TABLE II

NOMENCLATURE FOR MILL SCHEMATIC



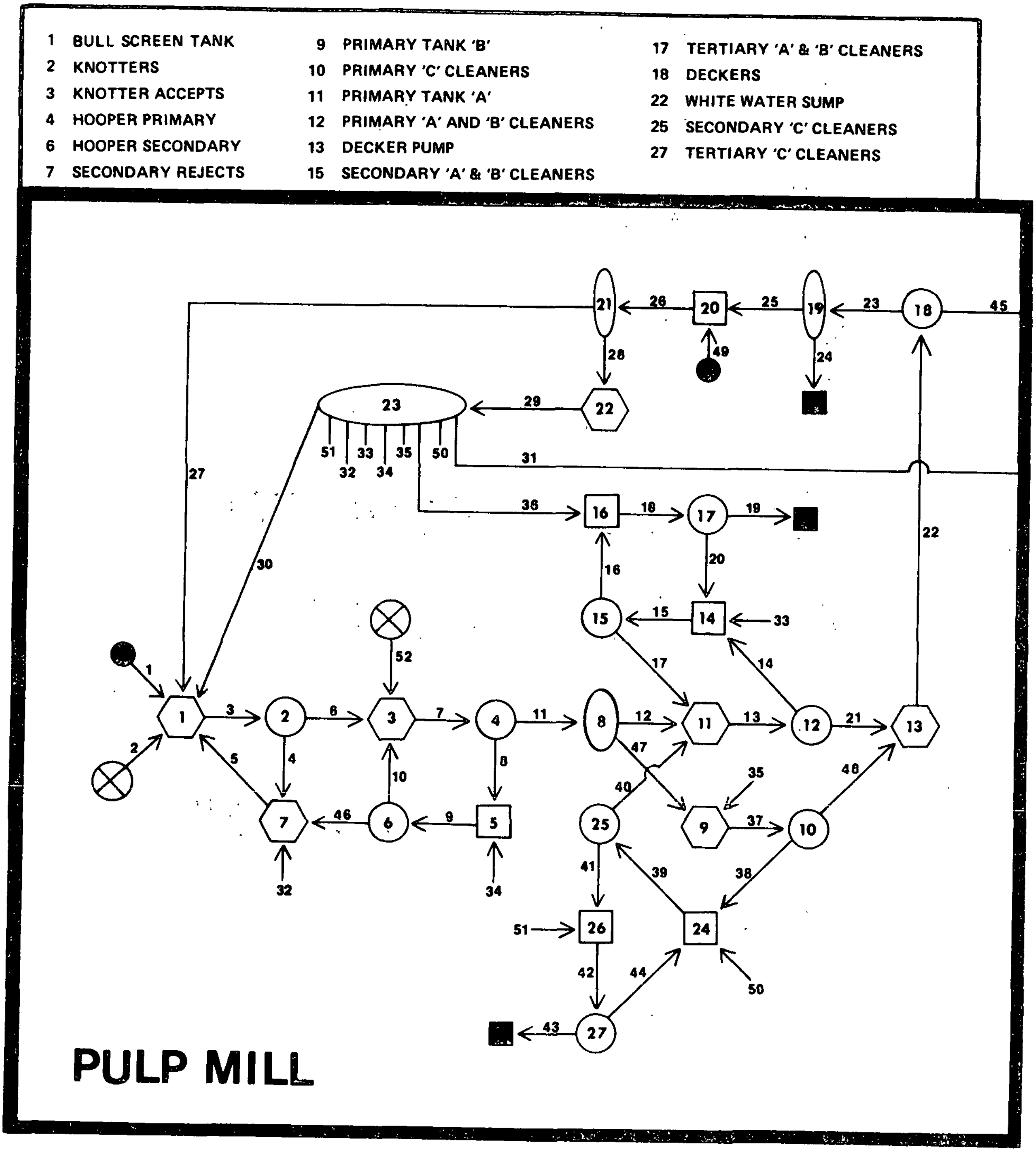


Figure 2. DYSCO Schematic of Pulp Mill

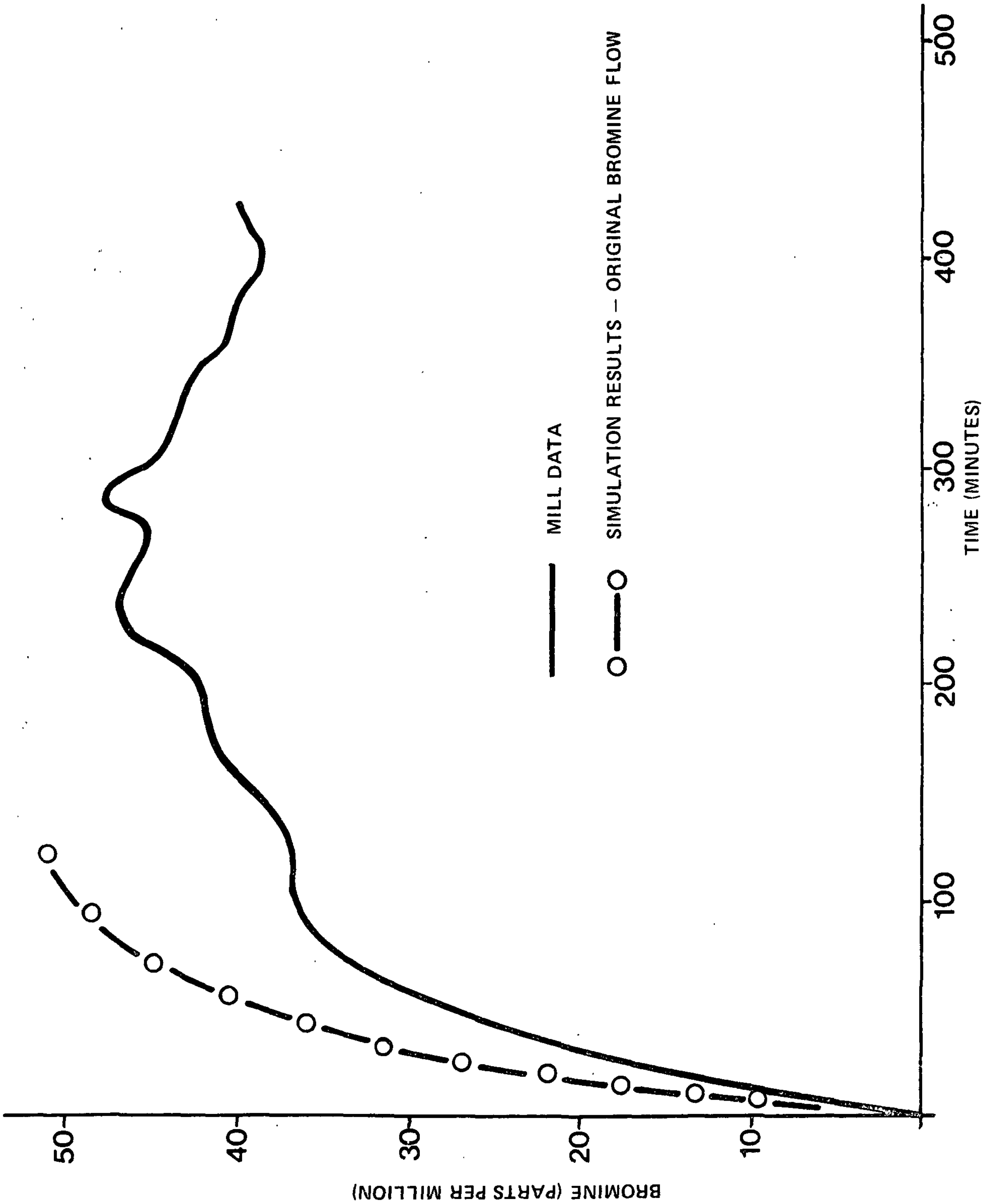


Figure 3. Bromine Concentration in Pulp Mill Process Water — Stream 23

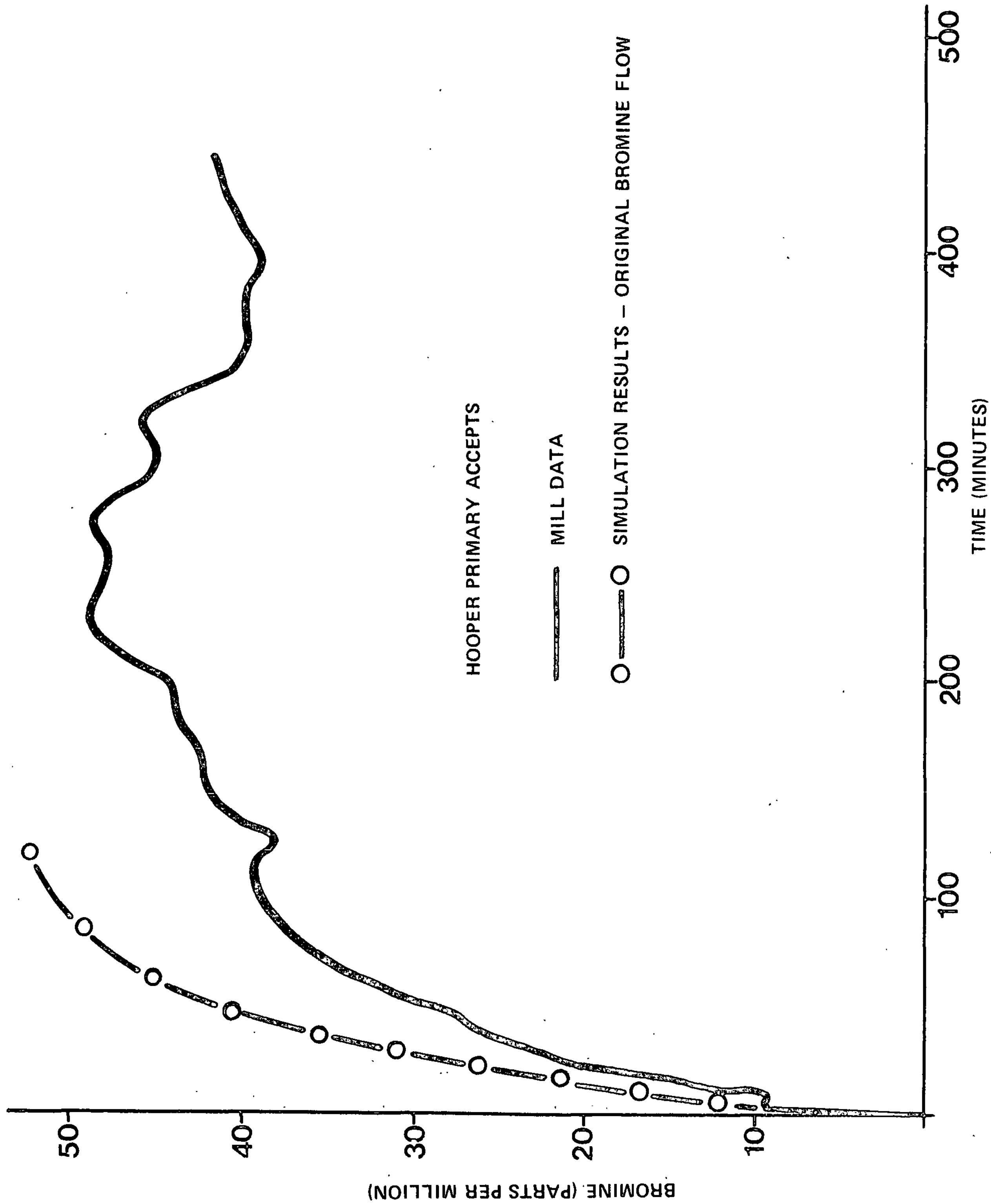


Figure 4. Bromine Concentration in Hooper Accepts – Stream 11

help determine the sensitivity of the process to various parameters and also determine if a particular parameter was in error. Stream flows and tank volumes were adjusted in this sensitivity analysis. With one exception, no reasonable combination of adjustments gave nearly coincident curves. The sensitivity studies showed that tank volume and stream flow changes greater than 100% would be required to bring the simulated data in line with the experimental results.

One exception did occur. When the inflow of tracer compound was reduced by about 23%, the curves coincided. This 23% flow reduction corresponds closely to the ratio of Br/NaBr (= 0.228). As shown in Fig. 5 and 6, the curves become nearly coincident up to the first flow upset at 90 minutes. A review of the experimental data shows no consistent analytical error. However, this simple correction makes the data suspect. Many of the fluctuations in the experimental curve can also be explained by flow fluctuations in the tracer injection line. A great deal of effort would be needed to match the two curves. With the good fit obtained in the first hour of the experiment, we concluded that the ability to simulate the mill was proven and it was not essential to explore possible means of fitting the remainder of the data.

Prior to developing the recycle scheme, the current mill ("open") system (Fig. 1) was simulated. The pulp mill had only two major inputs; fiber and water. For the pulp mill simulation, therefore, it was necessary to follow only three components in the water system, i.e., fiber, water, and bromine. When considering the mill as a whole, several other components become important. Bleach chemicals are added in the bleach plant; clay, alum, and minor amounts of other chemicals are added in the paper machine area. DYSCO could handle all these as separate compounds, but for each compound there is one differential equation for each

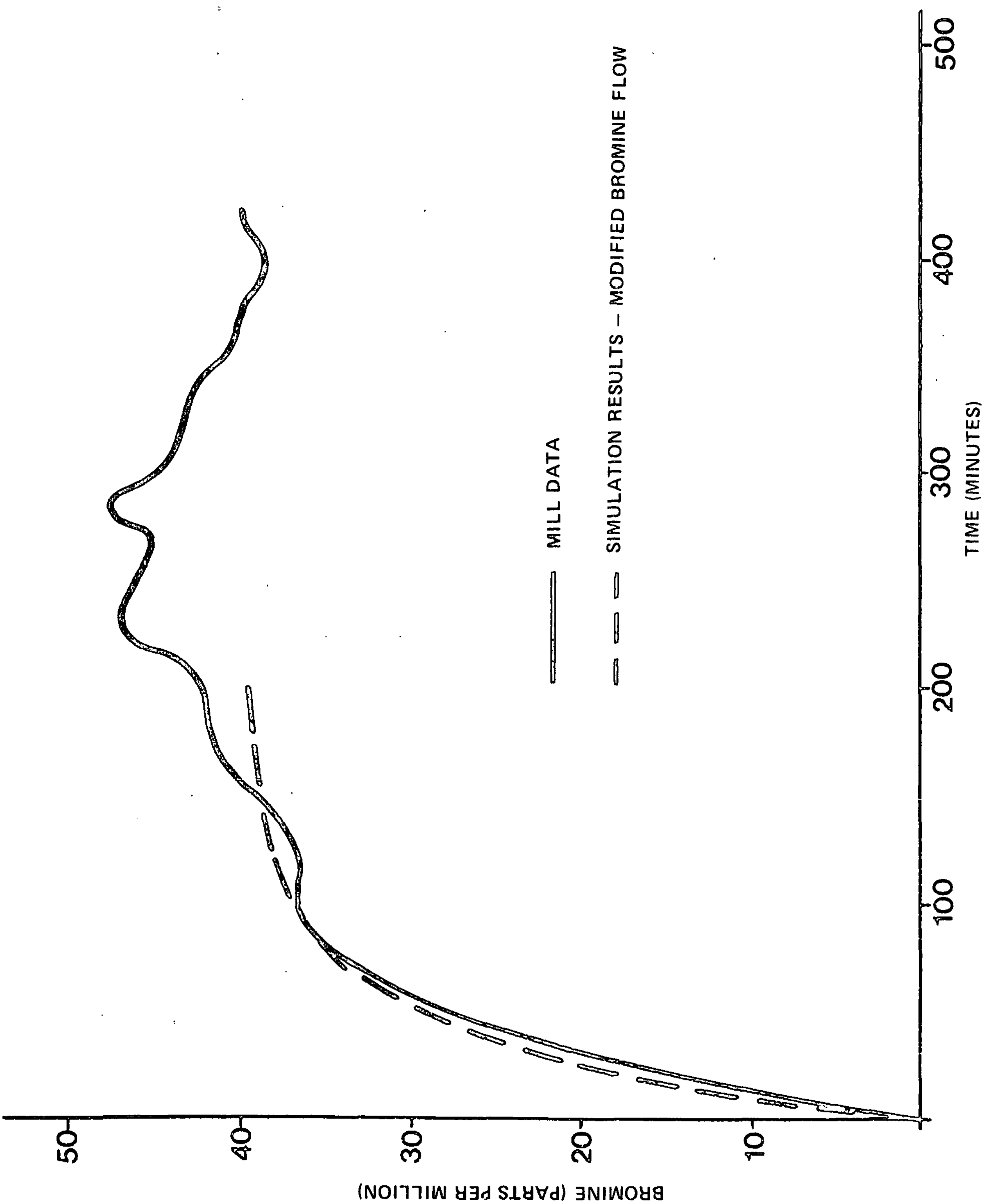


Figure 5. Bromine Concentration in Pulp Mill Process Water — Stream 23

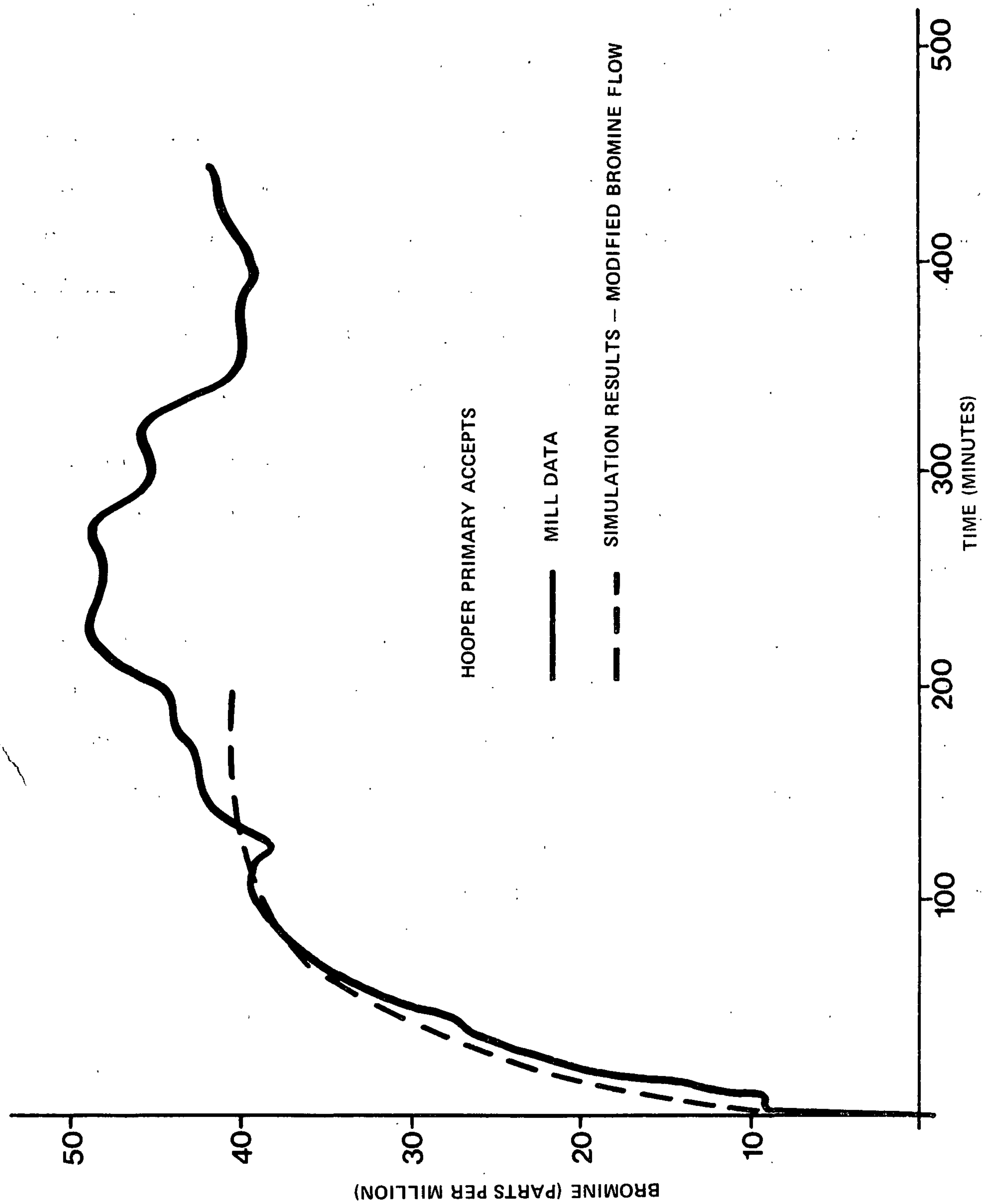


Figure 6. Bromine Concentration in Hooper Accepts — Stream 11

dynamic unit. To keep computer costs down and to reduce the complexity of the problem, all chemicals were lumped into two categories.

The dissolved material added in the clay (clay dissolved solids or CDS) makeup area was considered separately from the other dissolved solids. This was done as problems were expected when the clay suspension encountered other ions, such as aluminum. By separating the clay dissolved solids from the other dissolved solids, the mixing of the two types could be studied. (Note: The clay itself was not modelled — only those dissolved solids introduced with the clay.)

All other inorganic and organic dissolved materials were considered as one component, which, for convenience, is called dissolved solids (DS). The effect of this "lumping" is discussed later.

It is also important to point out that the term "fiber" refers to bone-dry fiber. The "water" component refers to free water and any water bound to the fiber. All component functions are represented as fractions of the total mass flowing in a pipe. Thus, the mass fraction of a dissolved solid represents the ratio of the mass flow rate of the dissolved component to the total mass flow rate. In general, this will not be equal to the concentration of this component in the free liquid phase.

The current DYSCO modules do not involve any fiber-chemical interactions. Thus the CDS and DS act as inert dissolved compounds. By adjusting separator efficiencies, more or less of these compounds tend to remain in the water system. Also, with any given separation efficiency, the highest levels of dissolved components will occur when there is no fiber-component interaction. Thus, these simulations tend to put an upper bound on the level of solids in the system. At the same time, of course, these simulations do not give accurate information about the level of CDS or DS in the sheet. The results of these simulations are shown in Fig. 7-17.

OPEN MILL SIMULATION

Figures 7 through 17 represent traces of various components through time at selected points in the mill. For convenience, various streams will be referred to by simulation stream number. For their location in the mill, please refer to Fig. 1. Stream 23 (Fig. 7 and 8) is the pulp mill water flume and is indicative of the water being reused in the pulp mill. Stream 79 (Fig. 9-11) is the pipe conveying stock from the bleach plant to the clay and alum area. The change in fiber composition is quite minor, from 3.6 to 3.8% consistency. The CDS are also quite low, leveling out around 25 ppm. The dissolved solids (Fig. 11) are rising slowly to the final state level (see Table III). Stream 179 (Fig. 12-14) is the stock flowing onto the wire of No. 2 paper machine. From Fig. 12, the incoming stock consistency varies slightly — from 0.4 to 0.5%, while the CDS drop rapidly to near zero. The DS take some time to approach steady state. Stream 144 (Fig. 15-16) represents the end of No. 1 paper machine, which is the sheet going into the dryer section. CDS make up an insignificant fraction of the sheet, whereas dissolved solids make up about 0.1% of the sheet.

The "open" mill curves of Fig. 7 to 17 show that the system behaves much like a first-order system. This is not totally unexpected, as the bleached groundwood storage tank has a time constant approximately 5 times the next largest process tank. Storage tanks in the clay and alum makeup areas have larger time constants, but they receive only steady flows and therefore do not affect the dynamics of the process.

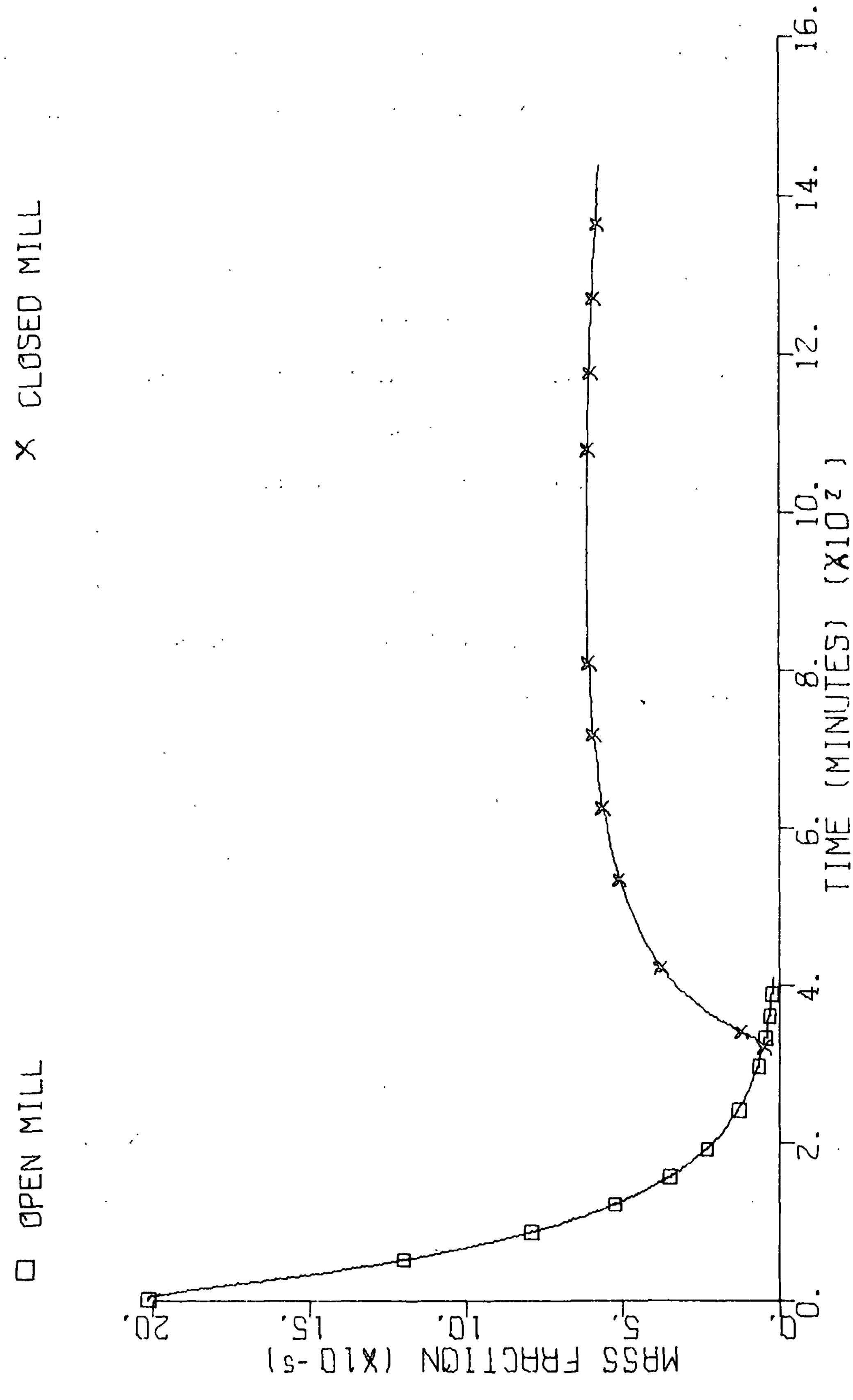


Figure 7. CDS in Pulp Mill Process Water — Stream 23

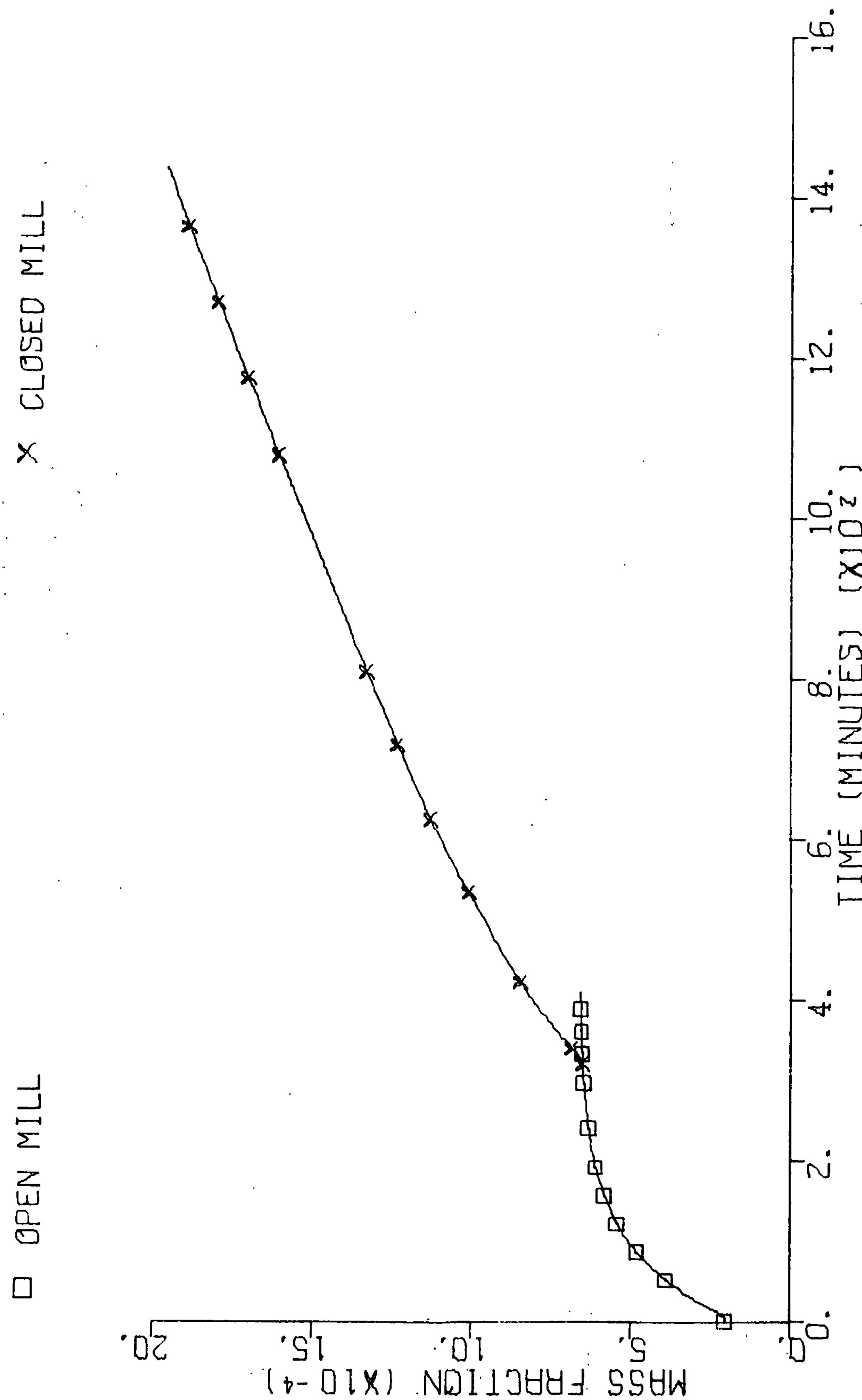


Figure 8. DS in Pulp Mill Process Water — Stream 23

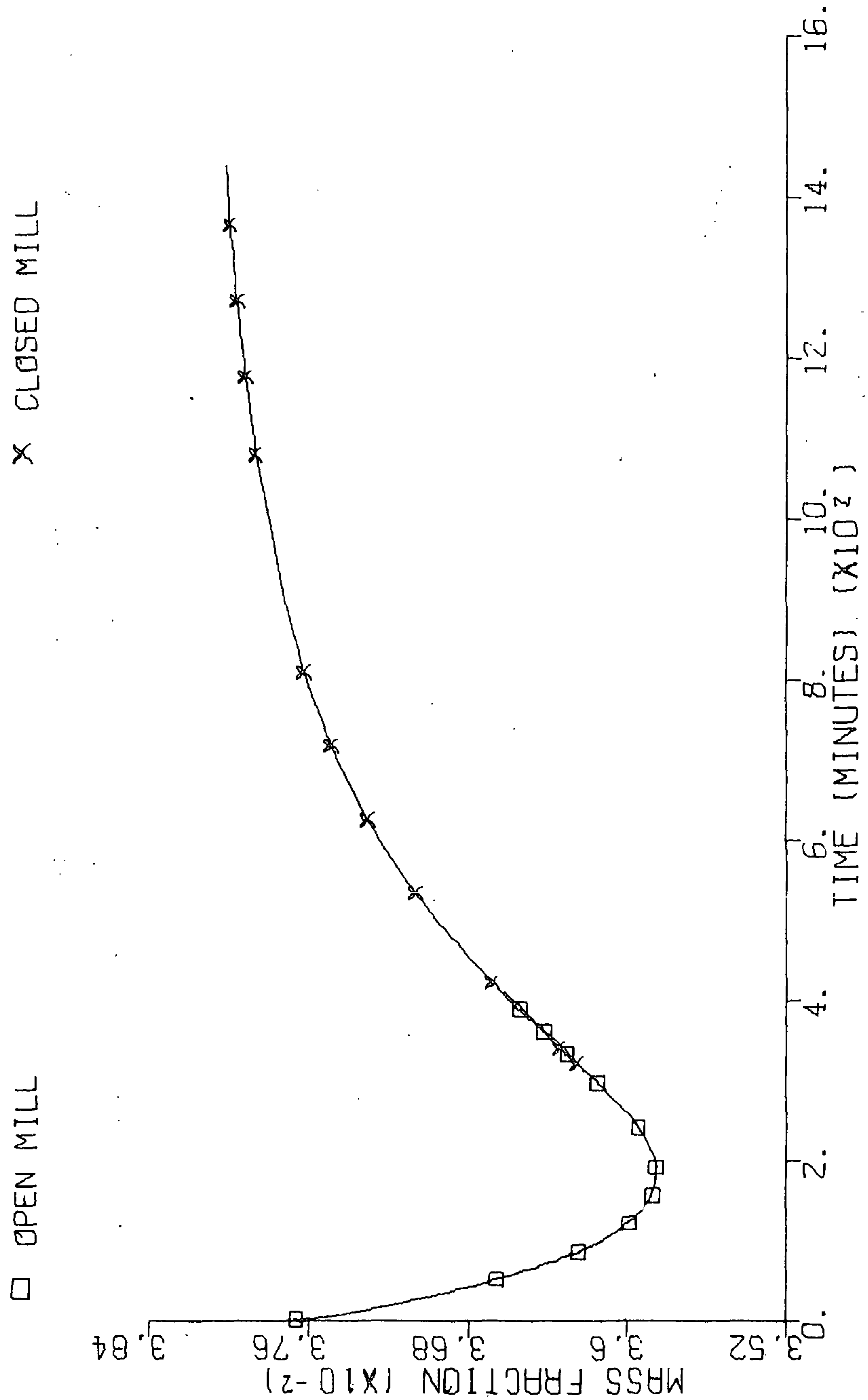


Figure 9. Fiber Leaving Bleach Plant - Stream 79

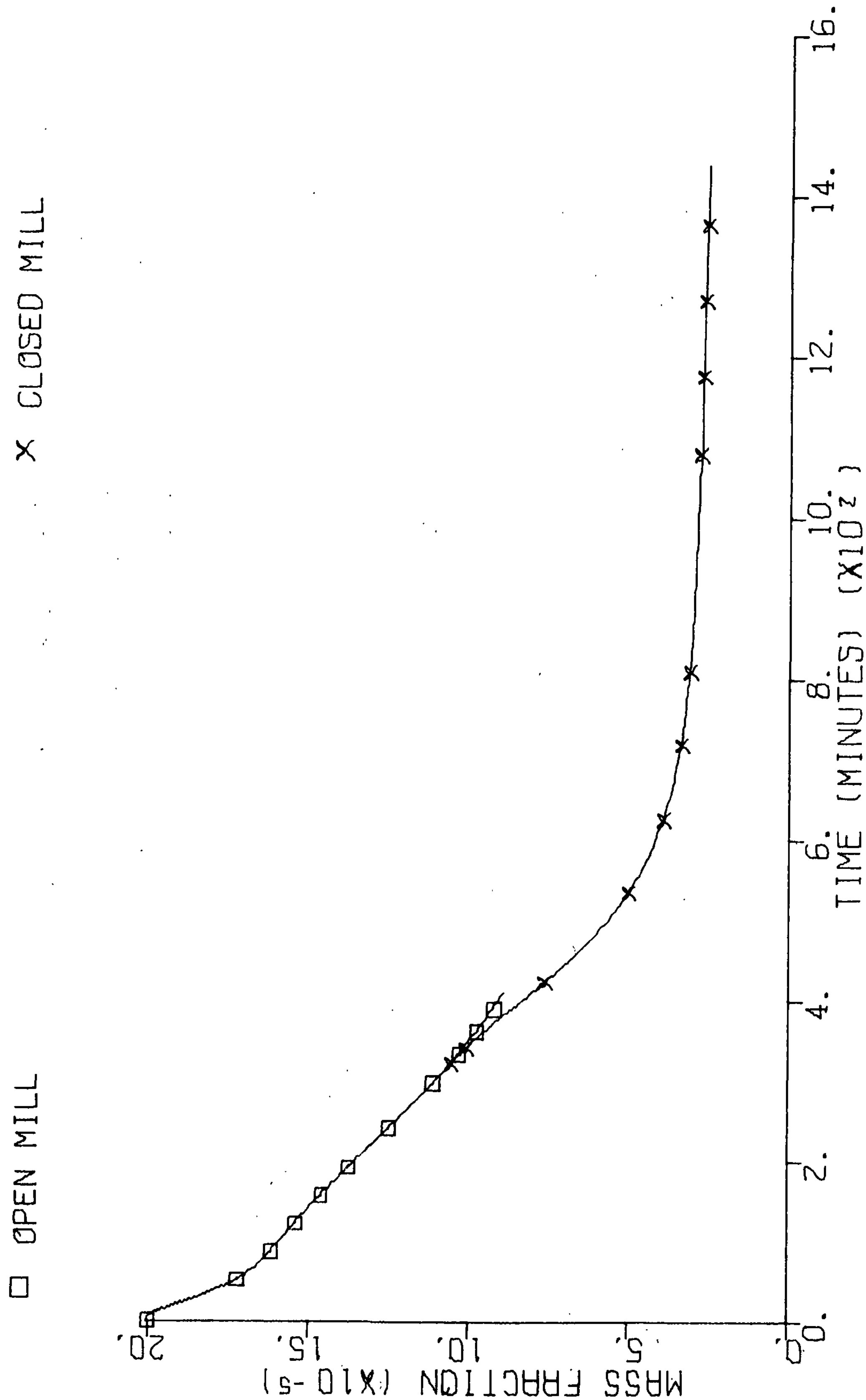


Figure 10. CDS Leaving Bleach Plant — Stream 79

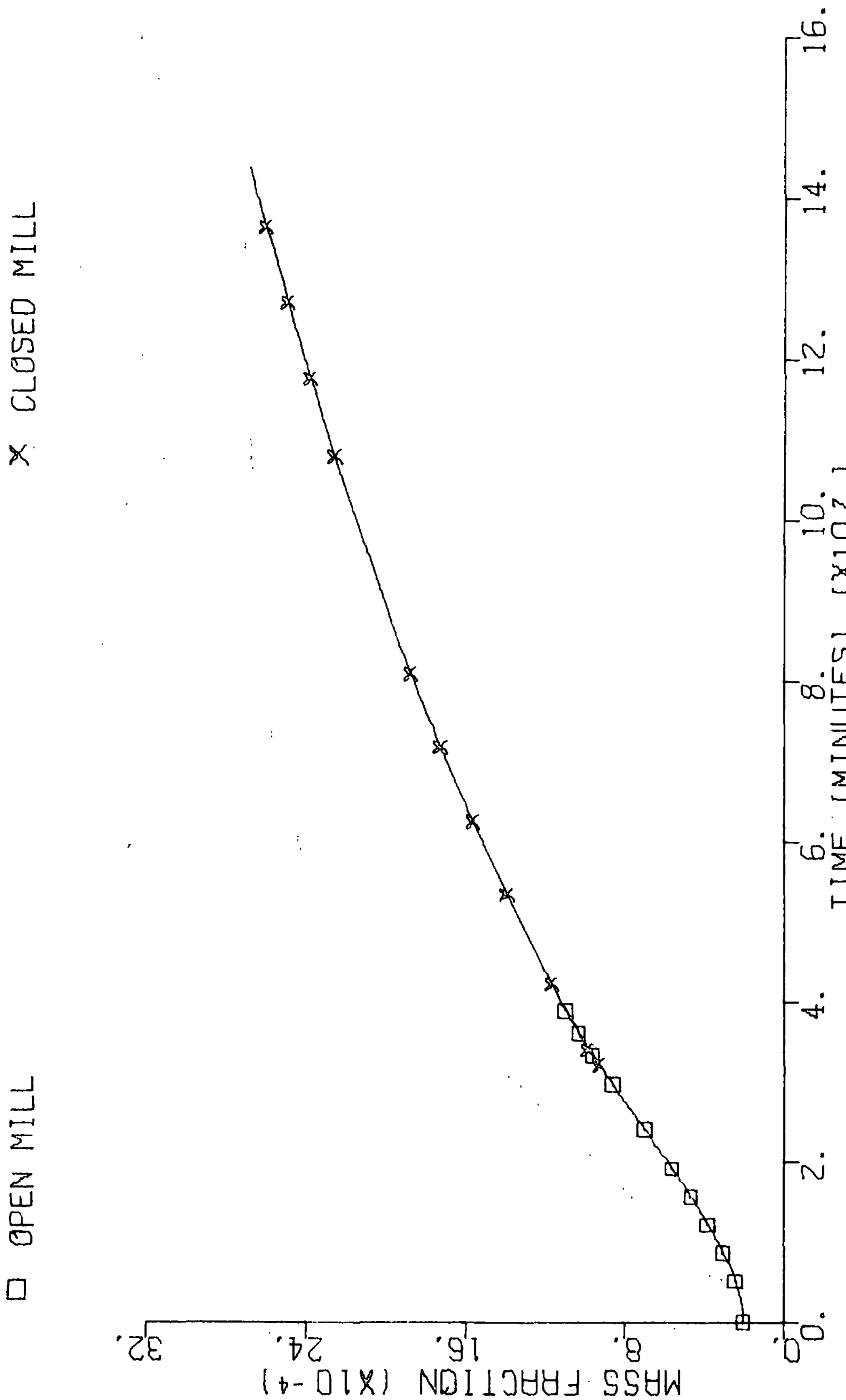


Figure 11. DS Leaving Bleach Plant — Stream 79

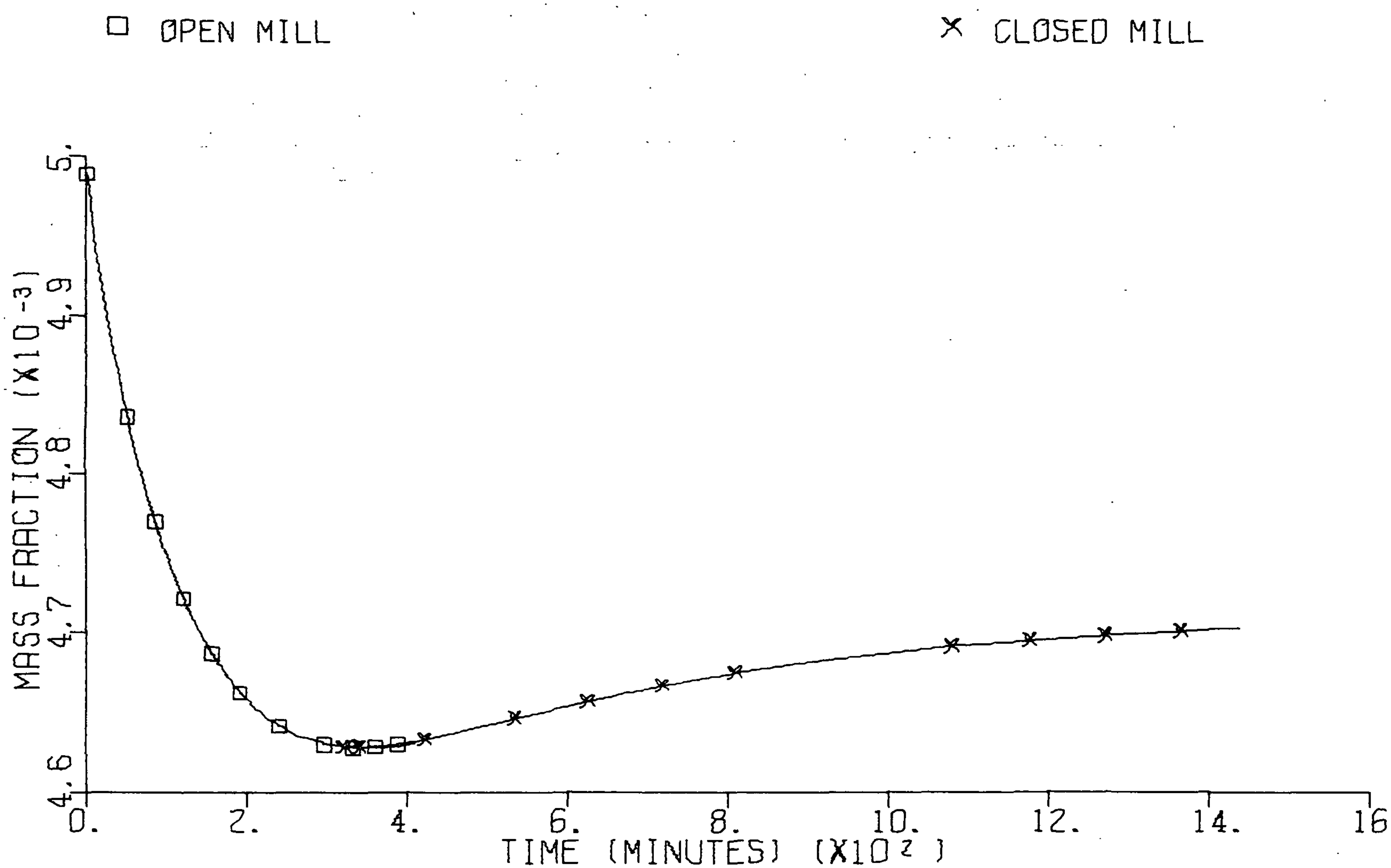


Figure 12. Fiber Leaving Headbox of No. 2 P.M. — Stream 175

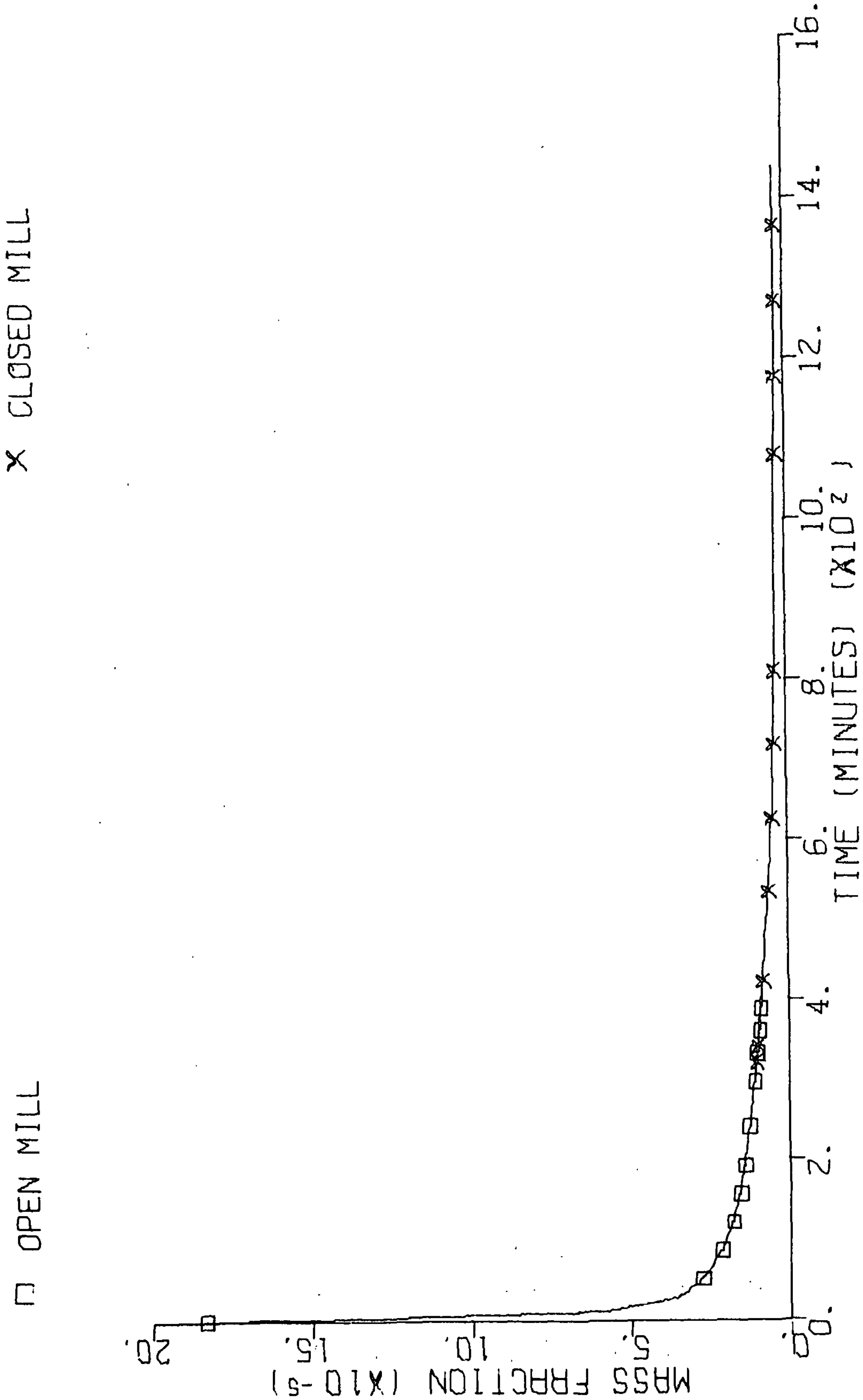


Figure 13. CDS Leaving Headbox of No. 2 P.M. — Stream 175

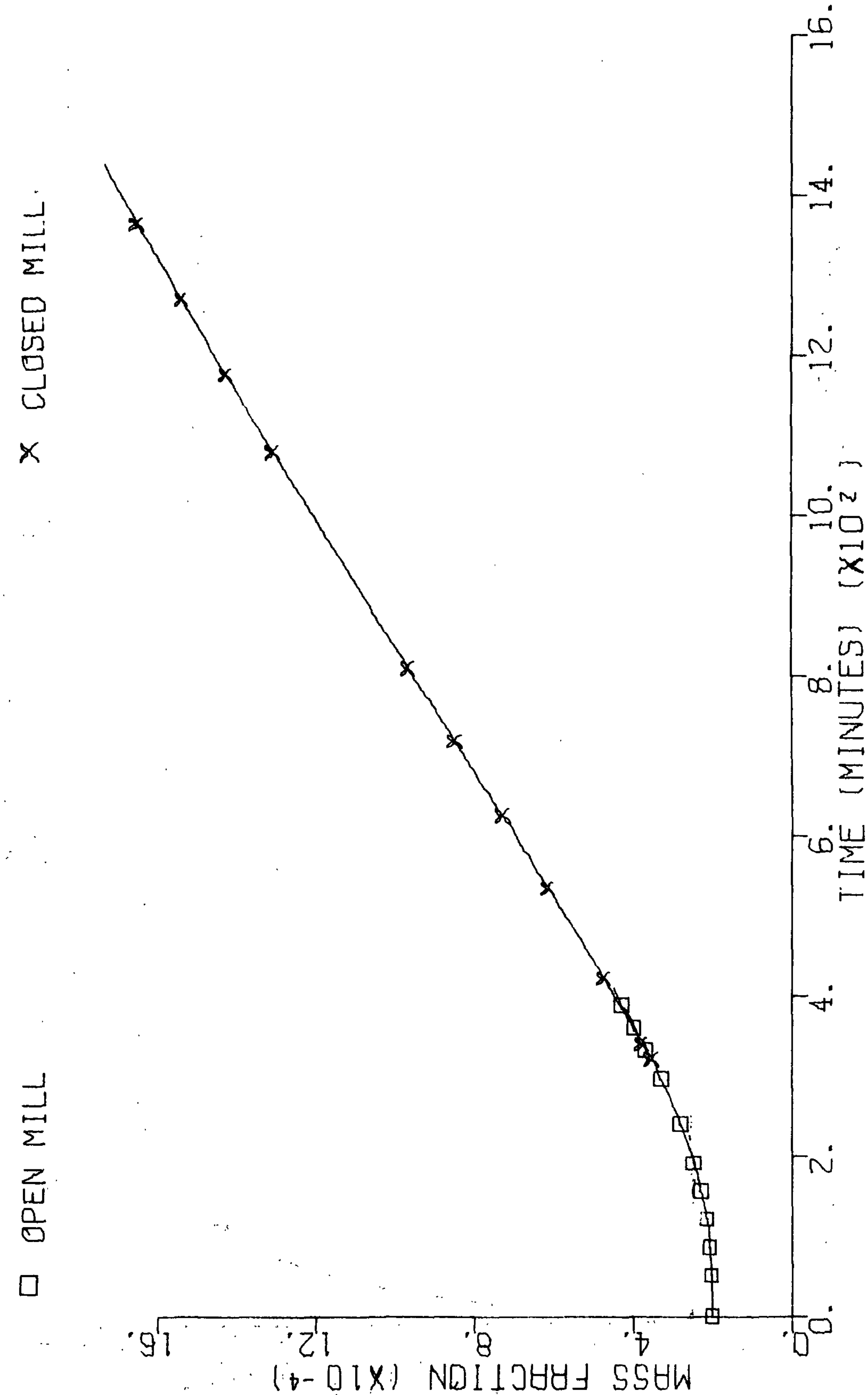


Figure 14. DS Leaving Headbox of No. 2 P.M. — Stream 175

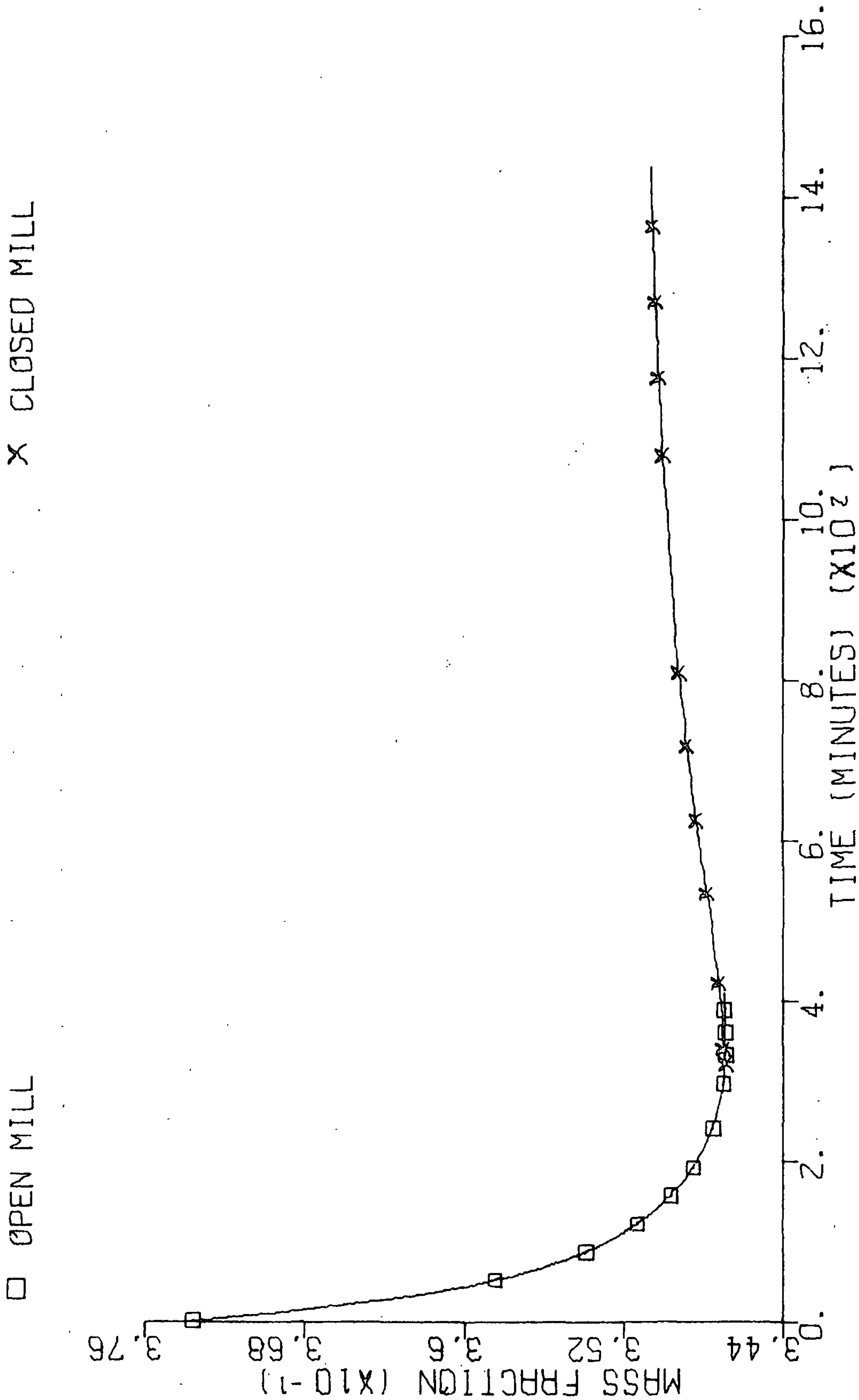


Figure 15. Fiber in Sheet to Dryer, No. 1 P.M. — Stream 144

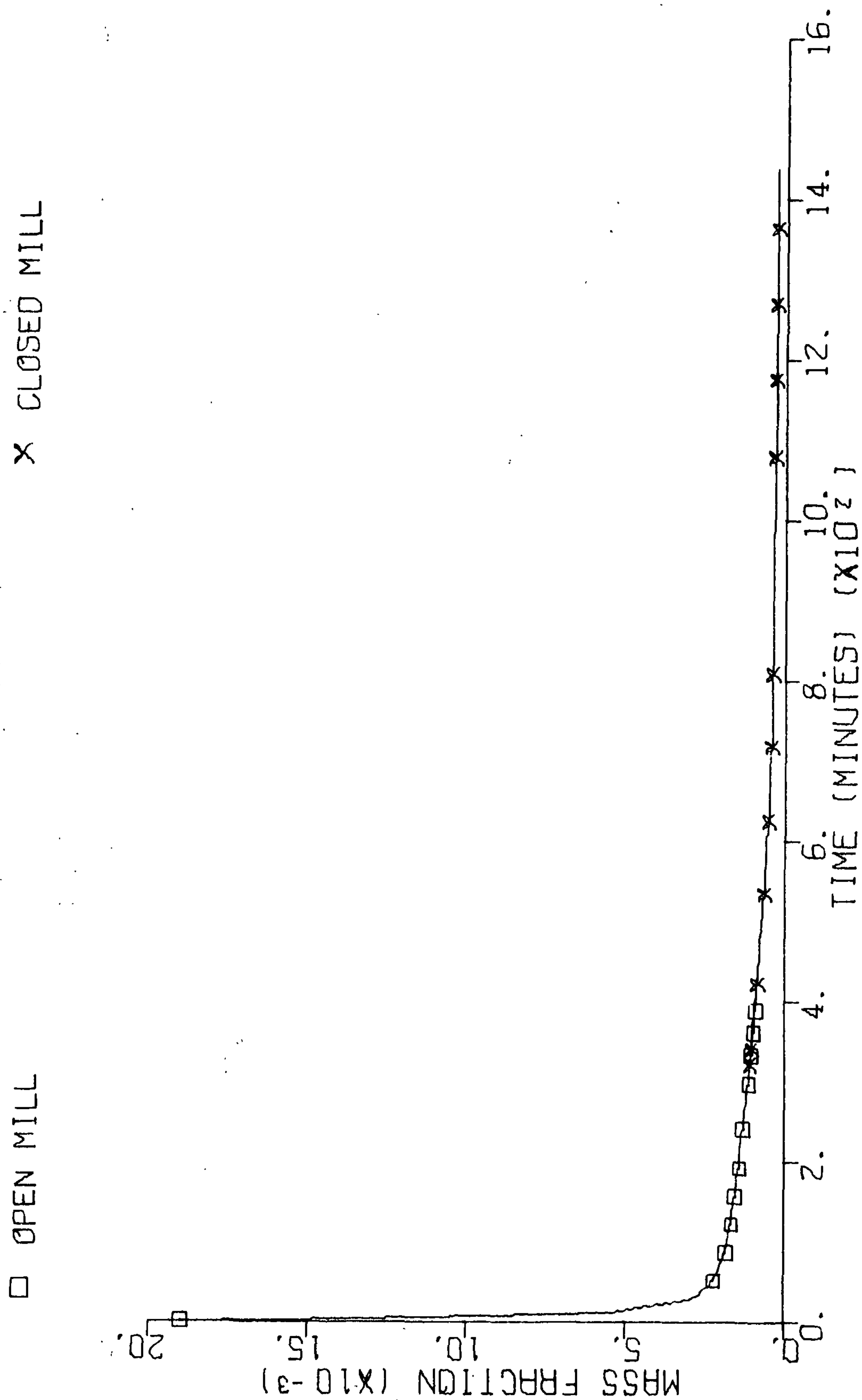


Figure 16. CDS in Sheet to Dryer, No. 1 P.M. – Stream 144

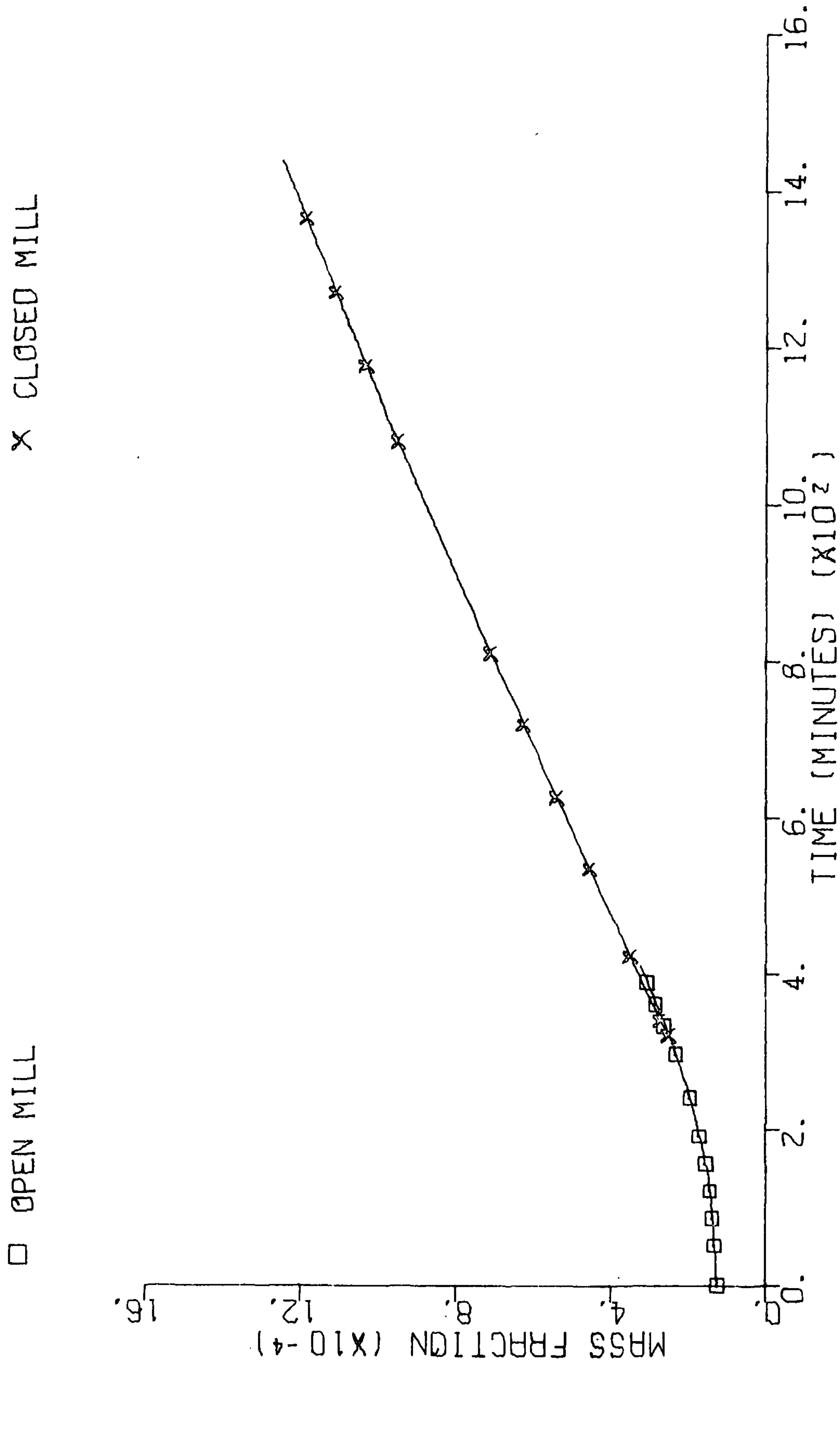


Figure 17. DS in Sheet to Dryer, No. 1 P.M. — Stream 144

CLOSED MILL SIMULATION

The "open" mill flow diagram shown in Fig. 1 has 11 sewers and 12 freshwater inputs. The mill water system was closed by using the 11 sewered streams to replace freshwater flows.

Freshwater to the pulp mill is replaced by collecting the sewered water from the pulp mill (Sewer S-3) and eliminating the pulp mill process water used for bleach plant dilution (Streams 69 and 71). Utilization of these flows to replace the freshwater in the pulp mill causes a heat buildup in the pulp mill. The bulk of the energy used to grind the wood ultimately adds to the sensible heat of the streams used to cool the grinders, thus raising the temperature of the pulp mill water system. DYSCO is capable of doing an energy balance, but the routines developed to date do not take advantage of this capability. Thus, no temperature rise predictions are made.

Excess paper machine white water is used to replace the pulp mill process water for bleach plant dilution water. A portion of the sewered flow (S-11) from the combined white water sump is sent to the bleach plant. This water will contain some fines and miscellaneous organic compounds as well as CDS and DS. In the current simulation, only a single fiber category is considered, thus a buildup of fines can not be predicted. Similarly, dissolved organic compounds were not modeled separately, so their buildup could not be studied.

We can, however, estimate the buildup of organic chemicals. The dissolved organic compounds primarily enter with the wood, while the dissolved inorganic compounds enter in the bleach plant and as alum. Thus, in the "open" mill, organics account for about 66% of the dissolved solids in the pulp mill and about 30% in the paper mill. In the "closed" mill case, organic compounds will account for about 30% of the total dissolved solids throughout the mill. This percentage is estimated from the fact that the ratio of organic dissolved solids entering the mill to the total dissolved solids entering the mill is about 0.30.

To complete closure, the remaining sewer flows (S-1, S-2, S-5 to S-11) are collected and screened to remove 90% of the fiber. The clear water from the screens is used to replace freshwater for clay makeup (Streams 235 and 238), bleach chemical makeup (Streams 66 and 76), machine shower water (Streams 136, 146, and 174) and paper machine dilution water (Stream 157). This reduces freshwater consumption from 940 gal/min to about 40 gal/min.

The appropriate piping changes were made to the simulated mill and the "closed" mill was modeled.* The results are also shown in Fig. 7 to 17. (Note: "Closed" simulations used the "open" mill simulation after about 400 minutes of simulation time as a starting point. This is why the "closed" simulations start at time of about 400 minutes.) The responses are typical for a set of tanks in series; the curves do not show the steady-state results for economic reasons. The groundwood unbleached storage tank has a holdup time of some 30 hours. Approximately three holdup times would be needed, at a minimum, to get the process within 95% of the steady-state value. This would require significant amounts of computer time, with little added value to the project goals.

The pulp mill, as evidenced by Fig. 7, reaches steady state quite rapidly. In the open mill case, when there is no recycle of paper mill water, the CDS wash out of the system in 4 to 5 hours. (The CDS were present strictly as all noninput streams and all tanks were initially set up with a fixed level

*The changes to "close" the mill are represented in red in Fig. 1.

of CDS and DS. There are no clay solids input to the pulp mill in the "open" case.) In the "closed" case, the pulp mill CDS levels are approaching steady state in approximately 4 hours.

The dissolved solids curves in Fig. 7 to 16 do not appear to be rising to steady state. This most likely is a matter of time. As mentioned above, a minimum of 90 hours would be needed to bring the process to steady state. Approximately 9.0 lb/min of dissolved solids enter the process, while the water consumption is 940 gal/min and 40 gal/min for the "open" and "closed" mills, respectively. The inlet water is assumed to have 200 ppm dissolved solids in addition to the 9.0 lb/min. Thus the approximate dissolved solids mass fraction throughout the mill should be 1.12×10^{-3} and 18×10^{-3} for the "open" and "closed" mills, respectively. The pulp mill dissolved solids mass fractions will be less than the 1.12×10^{-3} level in the "open" configuration as about 60% of dissolved solids are added in the bleach plant. Thus, pulp mill dissolved solids should be about the 5×10^{-4} level, which compares reasonably well with the 6×10^{-4} value of Fig. 8.

By reducing the volume of the unbleached groundwood storage tank, the steady-state levels of the various components can be predicted with greatly reduced simulation time. The dynamics of the transition from the current levels to the steady-state value are no longer applicable to the real mill, however. This was done for the "closed" mill case and the steady-state results are shown in Table III. These values compare well to the estimated values given above. In general, the level of CDS and DS are about 10 times higher in the "closed" mill than in the "open" mill. With this information, mill management could make decisions about how closure will affect mill operation and product quality. Before a final decision can be made, however, the energy balance must be done to estimate final temperatures.

TABLE III

STEADY-STATE VALUES FOR "OPEN" AND "CLOSED" MILL MASS FRACTION

Stream	Water		Fiber		Clay Solids		Inorganic Solids	
	Open	Closed	Open	Closed	Open	Closed	Open	Closed
23 (pulp mill)	1.00	0.982	0.0	0.0	0.0	0.848×10^{-6}	0.662×10^{-3}	0.179×10^{-1}
79 (bleach plant)	0.960	0.944	0.384×10^{-1}	0.379×10^{-1}	0.296×10^{-7}	0.383×10^{-6}	0.206×10^{-2}	0.185×10^{-1}
175 (#2 P.M. head-box)	0.994	0.978	0.474×10^{-2}	0.467×10^{-2}	0.755×10^{-6}	0.772×10^{-6}	0.185×10^{-2}	0.171×10^{-1}
144 (#1 P.M. sheet) at couch	0.646	0.634	0.352	0.364	0.108×10^{-3}	0.111×10^{-3}	0.115×10^{-2}	0.120×10^{-1}

CONCLUSIONS

Simulation can predict the changes in various components of mill water systems. With only one type of dynamic element, a capacitance unit, reasonably accurate predictions of the dynamic response of a mill to the injection of a tracer compound can be made. Thus, the simulator could be used to predict the dynamic response of the mill to various process upsets.

When an attempt is made to include each major tank in the mill in the simulation, a wide variety of time constants (volume/flow) results. The smallest of these controls the integration step, while the largest controls the amount of simulated time needed to obtain meaningful results. One compromise that can be made is to reduce small volume tanks to the status of instantaneous mix points. In this simulation, this was not done. The result of not doing this is that a large amount of computer time is necessary and a steady state may not be reached economically. When conducting a real mill simulation, as opposed to testing simulation technique, a careful analysis of the tradeoffs between inclusion of all dynamic elements and the costs of computer time needs to be made.

The project has demonstrated that a petrochemical simulator can be modified for use in the pulp and paper industry. DYSCO has proven to be easy to use, although somewhat expensive in terms of computer time. A mill flow sheet was relatively easily converted to DYSCO input. Rather simple models of the major processes resulted in reasonably accurate predictions of the dynamic response of the mill to a tracer injection. Further, analysis of the mill data indicate that, for the "closed" mill, some four days would be needed for the mill to reach steady state following a process change such as the addition of a new additive.

COMPUTER PROGRAM

DYSCO is a large program. It contains some 7,000 FORTRAN source language statements. The current version occupies about 500,000 bytes of memory, although this is somewhat machine dependent. We have run the simulator in timesharing and batch modes on two computers, an IBM 370/168 and a Burrough's B6700. One hour of simulation time for the full mill requires about 60 sec of CPU time on the IBM machine and 300 sec on the Burrough's machine. These comparisons are not exact, as there were slight differences in the piping diagrams, resulting in slightly different numerical integration time steps.

The computer code is available from The Institute of Paper Chemistry. We also have documentation available for the subroutines we have developed for DYSCO. Sample data decks can be obtained from IPC. The original source, Reference (2), should be consulted for the full documentation of DYSCO.

RECOMMENDATIONS

This project has shown the viability of dynamic simulation. Mills need this type of capability for process control and spill handling. We feel our major contribution would be to develop general flow diagrams for various types of mills and use these flow sheets to simulate alternative water reuse and spill control schemes.

These goals are quite different from the goals of Project 3251. Accordingly, this is the final report of this project. This important modeling and simulation work will be carried out under a new project number.

ACKNOWLEDGMENTS

The cooperation of the St. Regis Paper Company is gratefully acknowledged. Without the help of Mr. Russel Nipe at the St. Regis mill in Sartell, Minnesota and Mr. Bob Roscoe of the St. Regis Technical Center in Nyack, N.Y., the project could not have been conducted.

Thanks are also due to Dr. Brice Carnahan of the University of Michigan for making DYSCO available and to the computing center at the University of Wisconsin, Stevens Point, for help in converting the program from the IBM version to the Burroughs version.

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