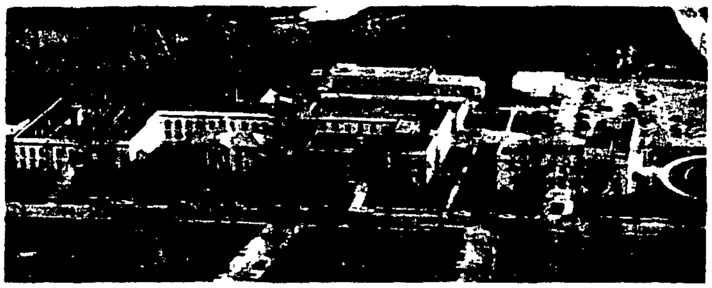

THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

HIGH TEMPERATURE PULPING OF LINERBOARD PULP

✓Project 2698

Report Three

A Progress Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

January 15, 1976

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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INTRODUCTION

It is generally believed that high maximum temperature kraft pulping degrades the resultant papermaking fiber and, therefore, temperatures in excess of 180°C are not ordinarily employed. It is postulated that the data generated to support this theory were obtained with pulping studies aimed at a high degree of delignification and may not apply to high yield linerboard pulps.

Accordingly, a limited research study was undertaken in the area of Exploratory Research for the purpose of determining the validity of the above hypothesis. The initial concept was rather broad and envisaged a possible switch to a different cooking chemical if the kraft pulping results proved negative.

The study was pursued in two phases: (1) an exploratory phase producing insufficient pulp for handsheet evaluation but allowing for an estimation of pulp quality in terms of viscosity measurements, and (2) repeat of the tests made in the exploratory phase on a scale sufficiently large to provide enough pulp for handsheet evaluation.

RAW MATERIALS

The exploratory phase of the research was carried out with southern pine chips available from previous research. Very large and very small fractions had been removed by screening. When the second stage was initiated, some pulpwood bolts from the same source were obtained. These were debarked, chipped, screened, and only the "on 1/4-inch" and "on 1/2-inch" chips were used.

A kraft white liquor was compounded from CP sodium hydroxide and technical grade sodium sulfide. The sulfidity was approximately 25%.

DISCUSSION OF RESULTS

In the initial cook the fresh pinewood was charged to the several vessels of a multiunit pulping device described by Thode, et al. (1). Each tube has a capacity of about 450 ml, and the addition of 95 g o.d. (150 g green weight) chips filled it to within about 1.5 inches of the top. A liquor ratio of 3.85 to 1 (basis o.d. chips and including water in the wood) provided coverage of the chips.

The technique called for preheating the oil to a chosen point before inserting the bombs. In the case of the control pulp, this was 100°C and the bath was brought to 176°C (172°C in the exploratory cooks) in 60 minutes. In the short time-high temperature cooks the bath was brought to within 10° of the desired maximum, the bombs were locked in place and all heaters were turned to full capacity. It usually took 20 minutes to reach maximum and required the addition of some cold oil at that point to prevent temporary overheating.

The pertinent data obtained from the exploratory digestions are given in Table I. Calculation of H-factor, a technique described by Vroom (2), was used to relate the degree of pulping achieved at the varying times of reaction with the maximum temperatures involved. The numerical values assigned by Vroom to the reaction rates at various temperature were based on measurements taken in the cooking liquor but they were used in this work with the only measurement available, the temperature of the bath. This accounts for the relatively large variation in the H-factor needed to produce pulps of the same degree of delignification since the time lags between the temperature of the bath and that of the digester contents would vary with the maximum temperature level.

TABLE I

HIGH TEMPERATURE KRAFT PULPING — EXPLORATORY PHASE

Max. Temp., °C	172	181			190			199		
Time to max. temp., min	60	15	15	15	18	18	18	15	15	15
Time at max. temp., min	65	11.5	16.0	20.5	7	11	13	1	2	3
H-factor	1725	1200	1350	1500	1200	1350	1500	1200	1350	1500
Kappa number	60.5	89.6	80.0	77.7	113	94.4	84.5	132	119	98.2
Yield, % (basis o.d. wood)	51.7	65.4	68.0	63.0	71.2	74.3	68.4	76.0	85.1	70.4
Screenings, % (basis o.d. pulp)	--	6.2	3.8	6.3	8.8	7.1	4.7	12.7	27.5	5.9
Viscosity, cp	39.7	36.6	35.6	43	49.9	49.0	43.4	61.6	52.6	37.0

Constant Conditions: Multiunit digesting apparatus
Temperatures measured on the oil bath
Fiberizing in Waring Blendor
Screening on 0.009-inch cut flat screen
Kappa number method T 236 m-60
Viscosity method T 230 su-66

The data obtained were sufficiently reassuring (Fig. 1) to initiate a move to produce enough pulp for a physical properties evaluation. The original proposal called for the use of a vertical stationary digester but when the work was actually scheduled, the apparatus was temporarily out of service. It was decided to make the cooks in the multiunit equipment, composite the products and pass the cooked chips through the disc mill.

A new batch of wood chips (even though from the original lot of pine bolts) and the use of a fresh supply of cooking liquor necessitated a new series of exploratory cooks. The data obtained thereby provided the pulping conditions

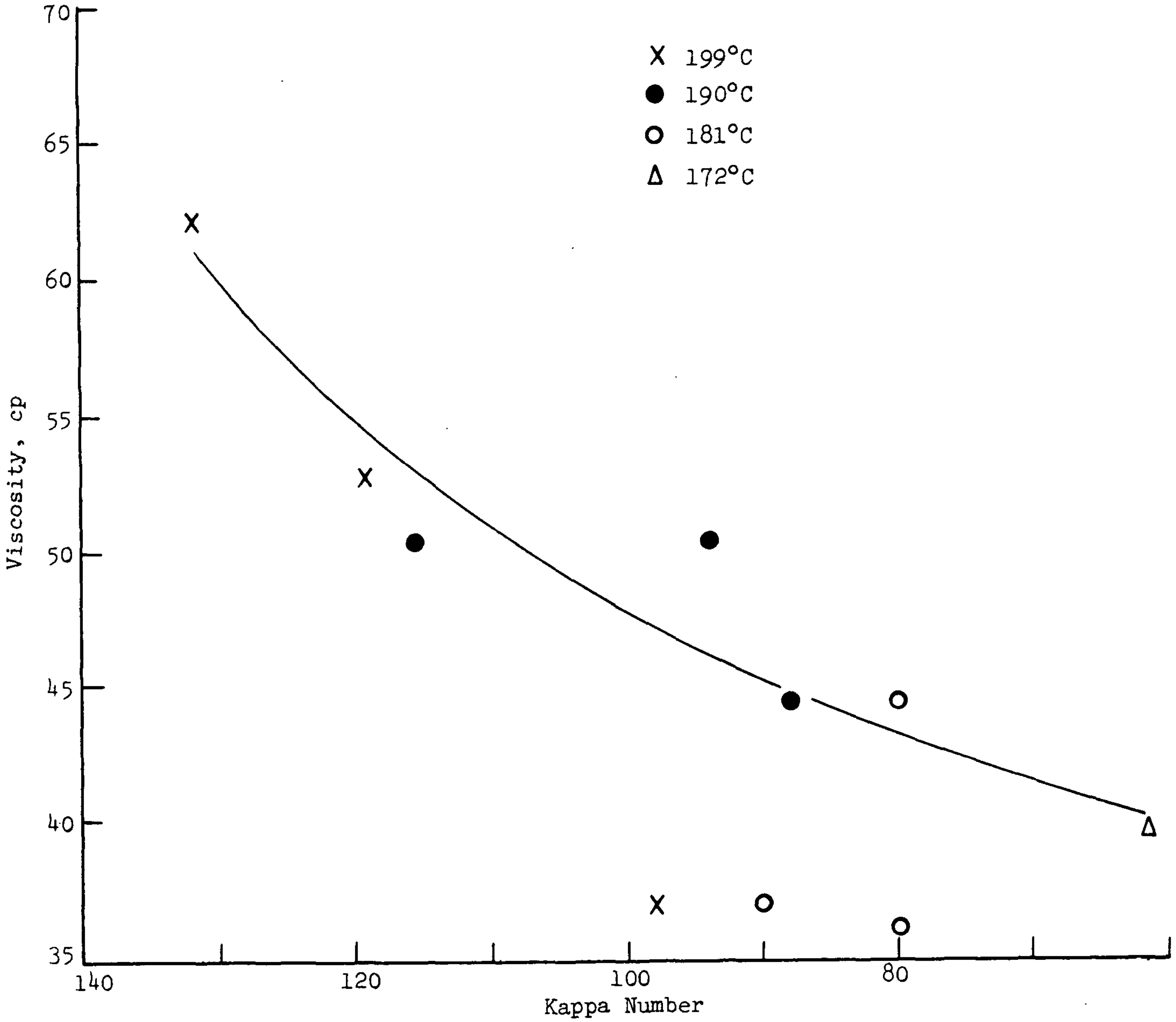

Figure 1. Exploratory Pulping Experiments. Relationship Between Kappa Number and Pulp Viscosity

shown in Table II. Four pulps were made, including a control where the temperature was brought to maximum slowly (i.e., in an hour instead of ca. 20 minutes). The H-factors used to determine the point of termination were 1000 for the control cook, 1300 for the 180°C cook, 1600 for the 190°C cook and 1900 for the 200°C. Translated into total cooking times this became, in the same order, 89, 44, 31, and 21 minutes.

TABLE II

HIGH TEMPERATURE KRAFT PULPING — EVALUATION PHASE

Cook	15 (control)	13	12	14
Maximum temperature, °C	176	180	190	200
Time to max. temp., min	60	17	22	20
Time at max. temp., min	29	27	9	1
Total cooking time, min	89	44	31	21
H-factor	1000	1300	1600	1900
Kappa number[a]	90	84.7	84.5	102
Yield, %[b] (basis o.d. wood)	55.1	56.4	54.4	57.7

Constant Conditions:
Multiunit digesting apparatus
Temperature measured on the oil bath
Fiberizing for yield, Waring Blendor
Fiberizing for strength, disc mill
Screening on 0.009-inch cut flat screen

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[a] From screened pulp.

[b] From single digester.

The combined contents of 13 vessels were heated with direct steam before fiberizing in a 12-inch Sprout Waldron disc mill. The No. 17804 discs were heated by direct steaming and hot chips, liquor and some water were passed between the discs, set at 0.008-inch clearance. The stock, at about 5% consistency, was washed free of chemical on a muslin covered wash box and screened on an 0.009-inch slotted screen. The rejects were removed and fiberized on a 1-gallon Waring Blendor. Returned to the screen, essentially all of the fiber was accepted. Yield and kappa number were obtained. The yield figures used in Table II are based on the ovendry weight of the contents of one bomb chosen at random, fiberized in a 1-gallon Waring Blendor and washed free of liquor on a fritted glass funnel. Kappa number determination was performed on the disc-milled and screened pulp. The kappa numbers come close to the target range of 90-110, with the 180 and 190°C cooks being somewhat below at ca. 84. The 200°C pulp was highest, 102.

The yield variation in the short cooks does not form a consistent pattern but all yields are greater than the 55.1% obtained from the control pulp. No immediate explanation can be offered for the lower yields recorded with the new chip batch. Table I suggests that yields in the 65-70% range could be achieved at 90-110 kappa number. This did not agree with data generated in other pulping studies, i.e., FKI Project 2926-3 where pine chips submitted by a member mill were pulped to 60-80 kappa number at yields of 50-60%. It is also noted that Thode (1) reported that pulping in the small bombs appeared to result in a lower yield than when parallel experiments were performed in a vertical stationary digester. It is conceded that this does not explain the difference in yields between the exploratory and the larger scale cooks.

Table III gives the physical properties measured after single beater evaluations of the four pulps. When this information was plotted against beating

TABLE III

PHYSICAL PROPERTIES OF HIGH YIELD KRAFT PULPS

Maximum temperature		176	170	190	200
Cook		15	13	12	14
Kappa number		90	84.7	84.5	102
Yield, %		55.1	56.4	54.4	57.7
	Beating Time, min				
Canadian freeness, ml	0	770	770	770	755
	15	765	770	770	770
	30	760	750	755	750
	45	720	710	700	710
	60	660	625	585	635
	75	535	480	410	445
	90	390	325	245	310
Sheet density, g/cc	0	0.350	0.355	0.389	0.343
	15	0.419	0.448	0.459	0.399
	30	0.477	0.498	0.502	0.453
	45	0.504	0.534	0.523	0.483
	60	0.540	0.555	0.535	0.518
	75	0.563	0.575	0.565	0.551
	90	0.593	0.604	0.593	0.557
Burst factor	0	25.8	19.2	20.4	19.1
	15	31.6	30.8	34.3	31.1
	30	41.0	42.4	41.7	37.7
	45	46.0	50.1	45.6	45.5
	60	52.5	53.4	52.4	47.9
	75	59.2	56.4	56.8	53.6
	90	60.3	62.3	62.0	56.1
Tear factor	0	198	173	193	182
	15	154	163	152	154
	30	142	144	133	136
	45	122	132	129	121
	60	118	121	122	117
	75	112	115	116	108
	90	105	113	111	107
Tensile (breaking length), km	0	3.98	3.53	3.96	3.71
	15	5.45	5.78	5.68	5.26
	30	6.56	7.04	5.90	6.37
	45	7.76	7.95	7.64	7.29
	60	7.75	8.53	7.23	7.75
	75	8.47	8.49	8.45	8.28
	90	8.51	9.17	9.27	8.43

TABLE III (Continued)

PHYSICAL PROPERTIES OF HIGH YIELD KRAFT PULPS

Maximum temperature		176	170	190	200
Cook		15	13	12	14
Kappa number		90	84.7	84.5	102
Yield, %		55.1	56.4	54.4	57.7
	Beating Time, min				
Stretch, %	0	1.1	1.1	1.1	1.2
	15	1.5	1.7	1.7	1.3
	30	1.8	2.0	1.7	1.6
	45	2.1	2.2	2.1	1.9
	60	2.1	2.3	2.2	2.2
	75	2.3	2.3	2.4	2.4
	90	2.3	2.6	2.6	2.3
Tensile energy absorption, kg m/m^2	0	1.62	1.47	1.70	1.61
	15	3.05	3.76	3.78	2.34
	30	4.60	5.48	4.00	3.93
	45	5.70	6.85	6.30	5.21
	60	6.27	7.88	6.20	6.62
	75	7.48	7.48	8.02	7.80
	90	7.54	9.62	9.98	7.75
Tensile stiffness, <u>Et</u>, kg/cm	0	340	322	355	329
	15	415	417	393	429
	30	431	445	381	439
	45	454	459	457	448
	60	477	502	404	455
	75	492	475	471	482
	90	482	507	505	491
Zero span tensile (breaking length), km	0	--	19.4	18.5	17.3
	15	18.1	18.3	18.8	18.1
	30	18.2	19.0	19.2	18.0
	45	18.3	20.1	19.4	18.9
	60	18.8	19.0	20.1	17.3
	75	18.7	19.3	19.2	17.5
	90	18.5	19.1	18.0	18.2
MIT fold	0	30	18	54	39
	15	229	165	319	156
	30	404	342	365	268
	45	453	414	377	323
	60	503	492	518	522
	75	626	634	710	531
	90	704	780	694	655

TABLE III (Continued)

PHYSICAL PROPERTIES OF HIGH YIELD KRAFT PULPS

Maximum temperature		176	170	190	200
Cook		15	13	12	14
Kappa number		90	84.7	84.5	102
Yield, %		55.1	56.4	54.4	57.7
	Beating Time, min				
Bendtsen porosity, ml/min	0	3370+	3370+	3370+	3370+
	15	3370+	3370+	3370+	3370+
	30	3370+	3370+	3370+	3370+
	45	3370+	3370+	3370+	3370+
	60	3110	2890	3160	2750
	75	1200	1110	674	840
	90	259	201	94	189

time, the graphs were used to produce the data shown in Table IV. Here comparisons are made at 700 and 450-ml Canadian Standard freeness. The short cooking time pulps were not as resistant to refining as the control as evidenced by the beating time to reach the two freeness levels. The sheet density at 700-ml freeness level was relatively unchanged except for the 200°C pulp which was marginally lower. The physical properties of the two highest temperature pulps are somewhat lower than the control but not markedly so.

With increased refining (to 450-ml CF) the differences seen at 700-ml freeness are reduced. Although the 200°C pulp is still somewhat low in most properties it actually compares quite well with the other pulps. Table V makes another comparison, this time examining the values at the point in refining where the burst factor reached 42. This point is reached at a higher freeness than used in the compilation of Table IV and at this degree of refining the four pulps are quite comparable in physical properties.

TABLE IV

COMPARISON OF PULP PROPERTIES AT TWO FREENESS LEVELS

Cook	15	13	12	14
Maximum temperature, °C	176 (Control)	180	190	200
Properties at 700 CF				
Time, min	54	49	45	47
Sheet density, g/cc	0.526	0.530	0.522	0.488
Burst factor	52	51	46.5	45
Tear factor	119	128	128	121
MIT fold	485	445	495	410
Tensile (breaking length), km	7.9	8.1	7.1	7.3
Stretch, %	2.1	2.3	2.1	2.0
Tensile energy absorption, kg m/m^2	6.3	6.9	5.9	5.4
Extensional stiffness, Et, kg/cm	475	482	450	450
Porosity, ml/sec	3370+	3370+	3370+	3370+
Properties at 450 CF				
Time, min	84	78	71	74
Sheet density, g/cc	0.583	0.582	0.560	0.549
Burst factor	61	58	56	53
Tear factor	108	114	117	108
MIT fold	675	680	640	570
Tensile (breaking length), km	8.4	8.85	8.3	8.1
Stretch, %	2.3	2.5	2.4	2.4
Tensile energy absorption, kg m/m^2	7.6	9.0	7.5	8.0
Extensional stiffness, Et, kg/cm	490	490	480	480
Porosity, ml/sec	520	860	960	880
Yield, %	55.1	56.4	58.6	57.7
Kappa number	90	84.7	84.5	102

TABLE V

PROPERTIES AT 42 BURST FACTOR

Cook	15	13	12	14
Maximum temperature, °C	176 (Control)	180	190	200
Density, g/cc	0.475	0.498	0.505	0.472
Canadian freeness, ml	750	750	755	725
Beating time, min	35	30	32	41
Tear factor	130	144	133	126
Tensile (breaking length), km	6.9	7.0	6.4	7.0
Stretch, %	1.8	2.0	1.9	1.8
Tensile energy absorption, kg m/m^2	5.0	5.5	5.0	4.9
Extensional stiffness, $\underline{Et}$, kg/cm	450	460	430	445
MIT fold	490	300	415	360

It is sometimes useful to examine the rate at which tearing strength drops as the bonding is increased by refining. Using bursting strength development as the measure of bonding, Fig. 2 shows that there is little to choose among the four pulps tested.

Handsheet swatches attached to this report show a slightly different color for the short cooking time pulps. They have a reddish cast not seen in the control pulp.

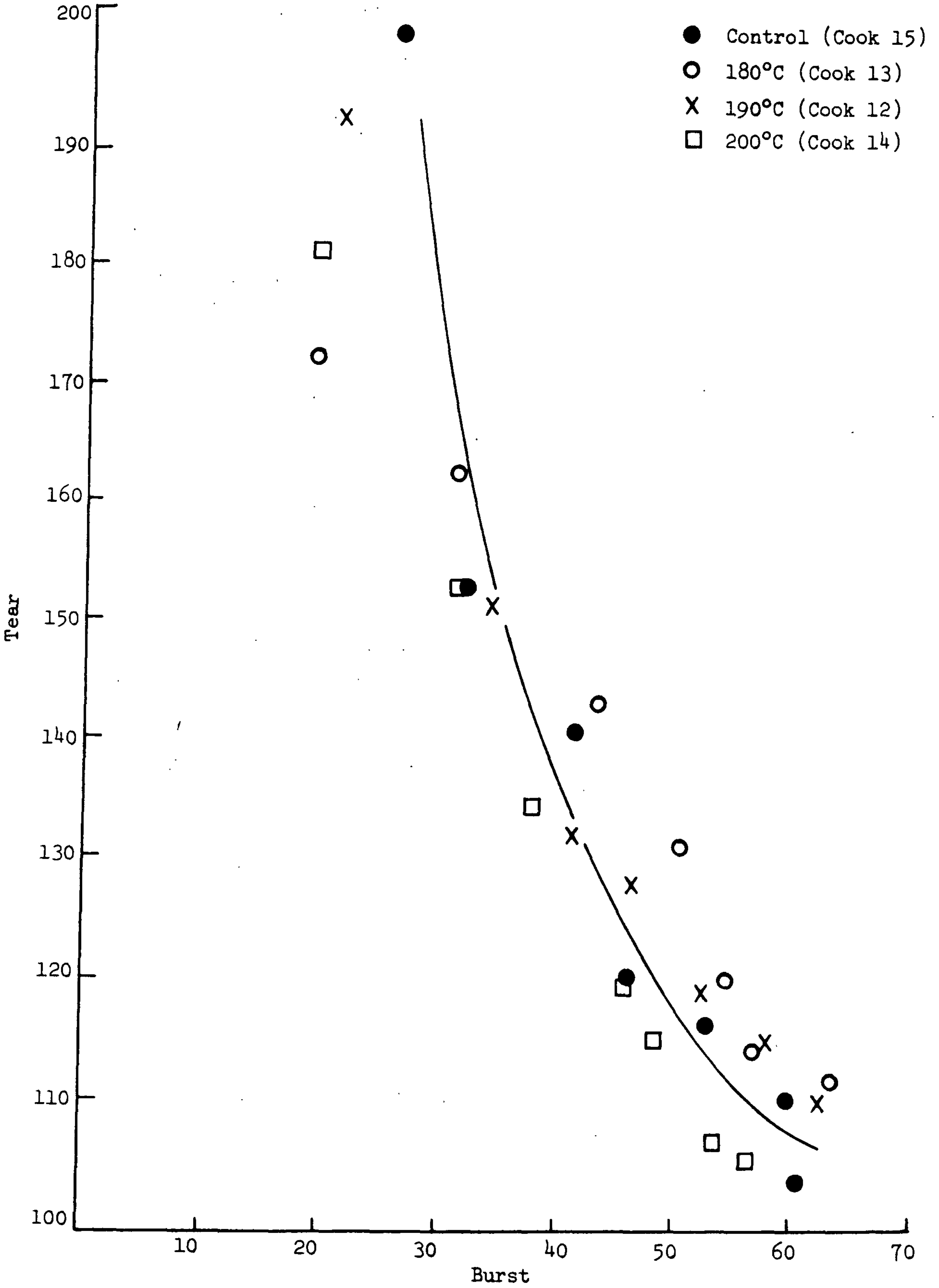

Figure 2. Tear-Burst Strength Relationship During Beater Refining

CONCLUSIONS

On the basis of the information derived from the laboratory-prepared pulps it would appear that no serious loss in pulp quality can be predicted if southern pine chips are subjected to a kraft cook using a type of digestion more commonly used in preparing high yield pulps for corrugating medium. It is visualized that both medium and linerboard pulps could be prepared in the same type of continuous digester. For example, a plant designed to utilize a kraft green liquor for making corrugating medium pulp from hardwood and a high-yield pine kraft pulp for linerboard could share digesting equipment and recovery facilities.

EXPERIMENTAL

The sample of loblolly pine used in this investigation was part of a shipment obtained for use in a graduate thesis. The exploratory cooks were made on chips from bolts processed immediately after the wood was received. In this instance the oversize particles and sawdust passing 0.25-inch screen were discarded. A larger supply was needed for the strength test pulps and two bolts were chipped after storing for about a year. Only chips passing a 0.75-inch mesh screen and retained on 0.5 and 0.25-inch screens were saved. In both cases, the chipping was done at the Institute in a 47-inch, 4-knife Carthage chipper.

All of the pulping was carried out in small bombs heated by immersion in a controlled temperature oil bath. The preliminary cooks were performed with 18% active alkali, expressed as Na_2O, the test pulps were made with 16% active alkali.

The wood, a measured amount of cooking liquor of known chemical content, and water as required to provide the proper water ratio were added to each digester. In the control cook the oil was at 100°C when the sealed vessels were immersed. In the short time-high temperature cooks the oil was brought to a point 10°C lower than planned for maximum. The electrical heaters used to increase temperature were controlled to bring the oil to the desired maximum temperature. In the case of the short cooks, this meant that all of the heaters were used at maximum load until the required temperature was reached. At this point additions of cold oil were made as necessary to keep the temperature from exceeding maximum.

At the end of the cook, the vessels were withdrawn from the hot oil and placed in a quenching chamber where they were showered sequentially with steam, hot water and cold water. From this chamber the partially cooled bombs were transferred to a tank of cold water where they were immersed until cool enough to handle.

After the vessels were opened, some of the spent liquor was removed for a test of pH level. Where the pulp was not to be used for strength tests, the liquor, the cooked chips, and water used in rinsing the bombs were added to a 1-gallon Waring Blendor and the chips were fiberized. The spent liquor was removed in a 3-liter fritted glass funnel. Copious additions of water followed to wash the last of the liquor from the pulp. The pulp pad was weighed and one-half oven dried to provide yield data, the remainder was available for chemical tests.

When the small vessels were used to accumulate enough pulp for strength evaluation the digestion was performed in duplicate. One vessel from one cook was segregated and treated as described above except that the entire pad was weighed for yield calculations. The cooked chips from the other 13 bombs, along with spent liquor and rinse water, were combined in a stainless steel pail and heated by direct steaming. Fiberizing of the hot chips took place in a 12-inch Sprout Waldron disc mill. The No. 17804 plates were heated with a jet of steam and set at 0.008-inch clearance. The pulp was washed free of liquor on a muslin covered wash box and screened on a small Valley flat screen fitted with an 0.009-inch slotted plate. The rejects were further defibered in the 1-gallon Waring Blendor until virtually the entire amount was accepted by the screen. Kappa number (T 236 m-60) and strength properties (T 200 os-70 and T 205 os-71) were obtained on this sample.

LITERATURE CITED

1. Thode, E. F., Peckham, J. R., and Daleski, E. J., Tappi 44(2):82(Feb., 1961).

2. Vroom, K. E., Pulp Paper Mag. Can. 58(3):228-31(Convention issue, 1957).

THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

STUDY OF THE CONTROL AND SENSOR DEVELOPMENT FOR AUTOMATED PRODUCTION OF CORRUGATED BOARD

Project 2698
Report 4

To The

Technical Division

Fourdrinier Kraft Board Group

of the

American Paper Institute

July 1, 1977

CONTROL AND SENSOR DEVELOPMENT
FOR AUTOMATED PRODUCTION OF CORRUGATED BOARD

Project 2698

Report 4

A Program Scope Report

to

Technical Division

Fourdrinier Kraft Board Group

July 12, 1977

Control and Sensor Development
for Automated Production of Corrugated Board

A Program Scope Report

I. Introduction

Corrugated board is currently produced with a machinery system that has little, if any, instrumentation for the on-line measurement of board characteristics. There is a similar lack of any automatic or feedback control equipment for the adjustment of the production process on the basis of measured values of board or component characteristics. Some plants measure board characteristics off-line on a regular or random sampling basis but such measurements are too infrequent or lag production by too much to be of value in the short-term control of quality or quantity of production. Roll stock characteristics are rarely used or even available although such information could be put to good use in a feedforward control scheme.

Some plants have automatic splicers, sychronized speed controls, automatic order changers, and various other pieces of equipment aimed at reducing the production loss from slow-downs for paper and order changes. These items help raise the average production speed but contribute to board quality only in that a steady rate of production tends to reduce quality variance. Such items as oil mist sprays, segmented water sprays, jet assists, ballast roller modulation, and others are incorporated in some machines but these invariably are manually controlled or programmed to machine speed. They are tailored to actual board characteristics only insofar as a skilled operator can observe and make intelligent process change decisions. Control is not based on measured data or well established process cause and effect relationships.

Despite the complexity of some corrugated board production systems, they still operate with a very limited degree of on-line quality assessment or control. This results in the production, often undetected, of inferior board; in unnecessary speed limitations imposed to keep quality within bounds; in excessive manpower and skill requirements; and in inefficient utilization of raw materials and resources such as energy. As the demands for higher or more efficient performance increase with fiber and processing costs, and as it becomes possible to construct a container of given performance with less fiber through better design, the quality control and efficiency demands on the corrugated production system will increase. Only through effective use of modern instrumentation and control technology will it be possible to meet the demands for efficiency and quality.

A concerted and systematic research and development program directed toward meeting the instrumentation and control needs of the corrugated production industry is clearly needed. In response to this need and given appropriate funding, the Institute of Paper Chemistry is prepared to establish a program which would have as its primary objective the development of the sensor and control concepts required to achieve on-line optimization of corrugated board production. Successful conclusion of this program would do much to improve the position of corrugated board with respect to competitive packaging materials.

II. Description of the Problem

From a control and instrumentation point of view the ultimate corrugated board production may be described by the diagram shown in Figure 1. This system includes means for selection and/or pretreatment of components; basic combining equipment; instruments for measuring board characteristics, process variables, and component characteristics; and a process controller. It is also necessary to include a container model to relate board characteristics to container performance since only the board characteristics can be directly controlled.

The objective of a corrugated board production system is to produce board in such a way as to optimize quality, production, and cost. It is the function of the process controller to keep the system running as close to the optimum as possible. To achieve this goal, the controller may adjust the process manipulated variables and it may also adjust component properties by selecting or pretreating roll stock. To make decisions about how these variables should be adjusted, the controller must have reliable information about the board being produced, about the current state of the process, about component properties,and about the targets for the current production run. Collectively these components make up a complete system for optimal control of corrugated board production. Each is described in more detail below.

Board Instruments

Board instruments serve three functions; to provide those data required to predict container performance, to provide data as required by the customer, and to provide the data required by the process controller. These data sets may have considerable overlap but must be viewed individually to assure that the total requirement for board data has been met. Typical variables that might be included are caliper, bond strength, flat crush, moisture, stiffness, etc. The most appropriate variables for inclusion in this group may be identified by processes of analysis to be discussed later.

Process Instruments

One of the important roles of the process controller is to adjust the process manipulated variables to achieve the desired end. To do this job well it will be necessary for the controller to have accurate information about current values of the process manipulated variables including such things as heater wrap angles, roll temperatures, operating speed, metering clearances and so on. It may also be necessary to measure certain process variables that are not manipulated, at least not directly. Medium and liner temperatures at key points in the process are examples of such variables. The role of the process instrumentation section of the system is to provide to the controller whatever process data are required to adequately control the process. Only through careful analysis can the appropriate variables be identified.

Component Instruments

Certain characteristics of the medium and liners are important in setting the process to achieve optimal performance. These characteristics can be measured by component instruments and supplied to the process controller to improve the control. Roll moisture is a good example of a component characteristic important to quality control. Other examples are caliper, receptivity, porosity and so on. These quantities may be measured as the material comes from the roll or they may be supplied to the control system from off-line measurements. In either case, the information is used to tell the controller to expect components with particular characteristics and to prepare accordingly. This is a good example of a feedforward control, a scheme that is very effective in compensating for the effects of changes in raw materials.

Control of Component Properties

To a limited extent component properties can be controlled by proper selection or matching or by altering the characteristics of the components by treatment. Matching of liners for roll moisture content is an example of the former; use of water sprays as aids to warp control and medium treatment agents as aids to forming are examples of the latter. It is expected that the process controller would have a role in component property control and this is so indicated in the diagram.

Process Controller

The process controller receives information from all of the instruments and from production targets set by the production manager and processes these data to determine and establish appropriate process settings. Thus the controller is the heart of the system. It may be as simple as an operator reading one or more instruments and adjusting one or more process manipulated variables in accordance with predetermined rules, or it may be as complex as a computer sampling numerous variables and using complex relationships to set the process, or it may be anywhere in between. The type of controller would not be set at this point, however, but should be determined by the goals of process contol and by the methods of analysis and development laid out below. Obviously, the controller should be the simplest possible subsystem consistent with the control objectives.

Combining Processes

While the general characteristics of the combining operation are well established and will not be changed to any degree by control considerations, the cause and effect relationships in this operation are not well understood. They must be established, however, if effective control is to be achieved. Process modeling is the key to identifying the manipulated variables that are really important to achieving the control objectives and to determining how the manipulated variables must be changed to yield a particular product change. Whether the controller is simple or complex, the relationships are still essential.

IV. Problem Solution

The problem of instrumenting and controlling the operation of a corrugated board production system as laid out above is that of typical multivariable control system. There are several variables to measure, several variables to manipulate, and several variables to control. These variables are expected to be related by a collection of process models or equations so that the overall problem is potentially quite complex. By applying a collection of well known and proven effective schemes of analysis to this system, however, it will be possible to reduce the system to the minimum degree of complexity necessary to achieve the control objectives.

It is suggested that the solution process include at least the following steps:

1. A thorough and comprehensive systems study to define the problem and its boundaries and the state of the art.
2. A modeling phase to identify or construct and evaluate the process interrelationships.
3. A sensitivity analysis to isolate or rank-order the measured and manipulated variables according to their influence on board characteristics and their value in describing process or board characteristics.
4. A feasibility study to assess probable success and cost for developing instruments and control concepts for those variables found to have a significant sensitivity.
5. A series of projects to develop and evaluate sensor and control

concepts. Each project would address a segment of the overall task with segment priorities identified from previous systems studies.

6. A continuous program monitoring scheme to regularly assess and evaluate the status and direction of the program.

Turning now to a more detailed examination of the program steps or phases, consider, first, the systems analysis. This is perhaps the most critical step in the solution process and certainly will provide the information on which planning for each of the other steps is based. Thus it must come first and be done carefully. The purposes of an initial systems study are to view the whole problem so that it may be clearly defined and bounded, to determine what is known and what is not known, to determine what is available and what is not available, and to determine what is important and not important. It is clear that instrumentation and control development for corrugated board production systems is in an embryonic state, that there are wide differences of opinion about the importance of various aspects of the process and the system, and also in the understanding of cause and effect relationships. The systems study will help to define the actual state of development in a clear and concise way and thus to establish a firm foundation for a long term development program.

The goal of the program would be development of the instrumentation and control concepts necessary to produce corrugated board in an optimum fashion. In carrying out such control, there are three important sets of variables as indicated before. These are the process manipulated variables, the controlled variables or board properties, and the component properties and other disturbance variables. Good control (high speed, high quality, low cost) requires that the manipulated variables be adjusted to optimize the product and production independent of the values of the disturbance variables. These variables are interrelated according to the physical lows and principles that govern and describe the various processes. The process modeling phase of the project would serve to identify or construct the required process models and to evaluate these models for validity with actual process data.

The sensitivity analysis phase of the program is designed to simplify the process models to the minimum degree of complexity sufficient to achieve the program goals. Reducing model complexity would simplify the analysis and development phases of the program as well as simplifying the final control system. This analysis is thus of great importance and must be conducted with commensurate care. In the overall process there are three sets of variables that are likely to be interrelated in some way so the potential complexity of the process models is great. Fortunately, however, a few variables can be expected to have critical significance with others playing only secondary or tertiary roles. Sensitivity analysis provides a framework for evaluating the strength of the interrelationships and thus of sorting out the few variables that must be considered. The value of such analysis lies first in simplifying the models and second in identifying and ranking according to importance, the variables to be measured and manipulated.

Systems analysis, process modeling, and sensitivity analysis will identify the critical variables to be measured and the critical process

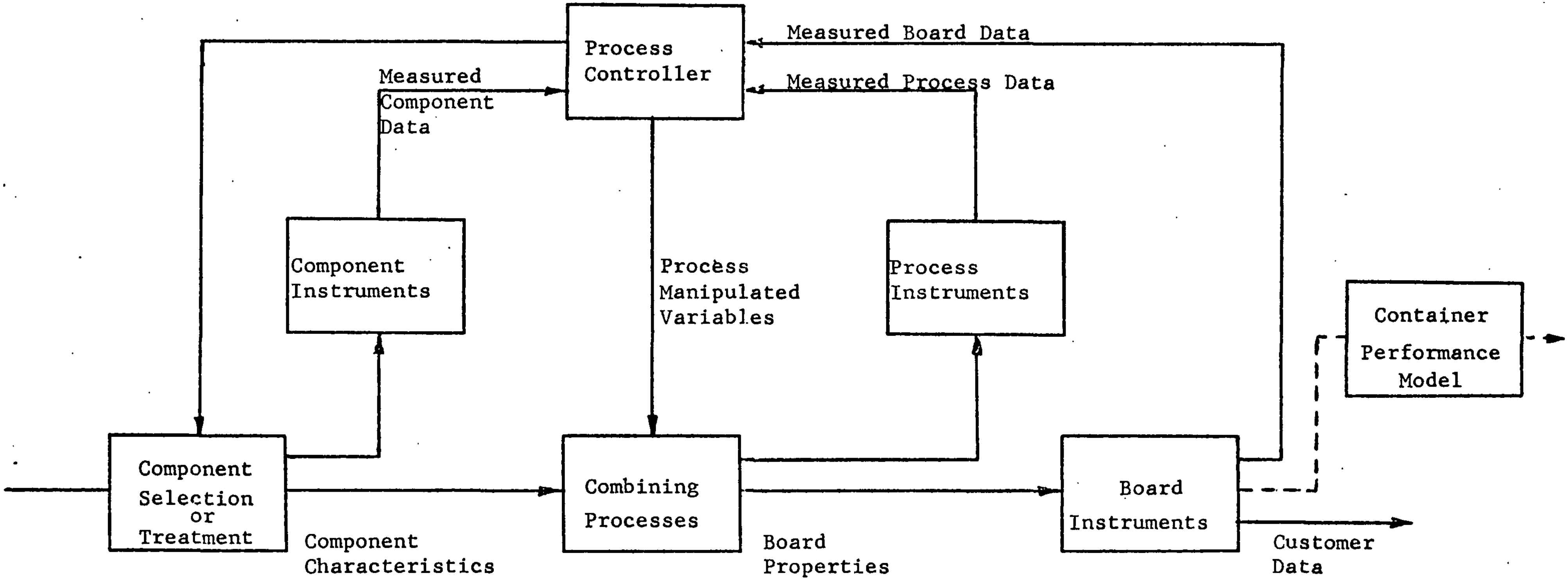

Figure 1: Instrumentation and control system for corrugated board production.

relationships. These procedures and the conclusions they suggest must be tempered, however, by measures of feasibility, practicality and probable success. On these bases the most cost effective development projects can be undertaken.

The overall control and instrumentation problem is too large to undertake at one time. It is therefore suggested that the complex program be assembled as a series of projects, the make-up of each project being determined by the preliminary studies discussed above. The first of these projects would be the systems analysis. Upon completion of the systems analysis and the resulting planning for subsequent work, the remaining tasks could be undertaken.

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