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ON-LINE FREENESS SENSORS USED IN MANUFACTURING OF PAPER PRODUCTS

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ABSTRACT

Generally, it is very difficult to predict stock drainage behavior on the paper machine, however, various drainage sensors have been developed to give some indication of paper machine performance with respect to stock drainage, and methods to automatically control refiners during manufacturing of paper products. The purpose of the paper is to provide an overview of the existing freeness sensors and describe their operating principles, and variables which may influence their measuring accuracy.

INTRODUCTION

Drainage of a pulp suspension on the paper machine wet end is one of the most important variables that influences the quality, productivity, and efficiency of the papermaking. Generally, it is very difficult to predict stock drainage behavior on the paper machine; however, various drainage testers have been developed to give some indication of paper-machine performance with respect to drainage characteristics, and provide input for automatic control of the refiners.

Freeness is a measure of the rate at which water drains from a pulp suspension through a mesh screen or a perforated plate, and it is measured to assess drainage characteristics of stock during stock preparation at some location before the paper machine head-box. This quantity which depends upon the pulp stock, fiber flexibility, and the fines content of the pulp, can be used as an indication of sheet formation, and final sheet properties such as tensile strength, burst, tear, and fold. With an accurate on-line freeness measurement, papermakers can identify causes of stock variation. Then, by adjusting the furnish component, amount of recycled pulp, and refiners load, they and minimize or eliminate the stock variation, and increase production efficiency through. Improved uniformity of stock drainage on the wire leads to efficient drying and less load on the refiner, thus, reduced energy costs; higher production; and improved paper quality.

Laboratory methods such as the Williams freeness test (1), the Canadian standard freeness (CSF) test (TAPPI T227 om-85), TAPPI drainage (TAPPI T221 om-93), and the Schopper-Riegler freeness (SR) tests (SCAN C19:65) have been developed to measure pulp freeness. The William freeness tester and TAPPI drainage measure the time required for a fixed volume of water to pass through a wire screen from a fixed volume of stock sample. The CSF and SR freeness testers measure the volume of water that drains through a perforated plate from a fixed volume of stock collected in a cone. The above two tests use the principle of divided flow. The cone has two discharge orifices one of small bore at the bottom, and the other of larger bore in the form of a side arm. Among these off-line methods, the CSF is widely accepted technique by the paper industry in the United States. A high freeness number represents a faster drainage rate in the CSF test.

It should be emphasized that these tests methods determine the pulp freeness under conditions that are completely different from those in the paper machine, and the measured values may have little relation to the drainage of stock on the machine wire (2). However, the results are still very valuable with respect to guidance of operation of mill components such as beaters and refiners. Some studies have applied Darcy's law to these freeness testers to develop theoretical models for pulp freeness based on filtration principles (3,4).

On-line freeness measurements is based on sensing of some properties that are related to freeness, and the measured quantities are expressed in terms of freeness. Because of this indirect measuring method, variables other than freeness may affect the signals produced by the sensors. Temperature and consistency are two important variables that can have a significant influence on freeness measurement. Standard temperature and consistency for laboratory measurement of CSF are 20°C and 0.3 %Cs, respectively. At higher temperatures, viscosity of waters drops which results in greater pulp freeness (CSF). For instance, a ±10°F change in stock temperature can cause as much as 12 percent variation in freeness in the operating range of 400 CSF. During laboratory measurement of freeness, a consistency variation of ± 0.1 %Cs (compared to the standard of 0.3 %Cs) can cause as much as ±15% change in freeness in the same range. Because of this strong sensitivity of freeness to pulp temperature and consistency, appropriate correction tables for these variables are provided in the TAPPI test methods (TAPPI T227 om-85). Other variables such as furnish type, furnish treatment, amount of fines, test method, additives, stock flow rate, line pressure, PH, entrained air, and dissolved salts may have some influence on freeness measurement.

DESCRIPTION OF SOME COMMERCIAL ON-LINE DRAINAGE TESTERS

In general, most on-line freeness testers operate based on filtration principle in which water is extracted from a pulp suspension through a screen, and its drainage rate through a fiber mat that is formed on the screen is measured. Most sensors (e.g., Drainac IIB, Innomatic 63M-7, and KOEI) freeness testers operate in batch mode. In these sensors, the amount of time it takes for a fixed volume of filtrate to be extracted from a fiber mat under a fixed pressure differential is measured, and used as an index of the pulp freeness. Sensors that operate in continuous mode consist of a tank and a rotating cylindrical drum covered with a screen. A pulp sample is continuously feed into the tank. For a fixed liquid level in the tank, the flow through the screen is measured and correlated to freeness. These types of sensors have not gained popularity by the pulp and paper industry (5). The following sections provide a general description of some of the freeness testers that operate in batch mode. Additional information can be obtained from each instrument operating manual and other literature (e.g., references 5-7).

I. INNOMATIC 63M-7

The Innomatic 63M-7 freeness analyzer (8) can be connected to a process line by using a bypass (shunt) line that allows for maintenance or shutting down of the sensor without interrupting pulp flow through the process pipe. The sensor has a microprocessor base electronics cabinet for control and readout which is separated from the analyzer. The analyzer consists of an open-ended stainless steel (SS) inner tube and an outer SS vessel (Figure 1). The stock pulp from the by pass line enters the outer vessel and fills the inner tube to the same level as the outer vessel. Then, from the outer vessel gravity discharges into a chest. The sample pulp column in the inner tube is connected to another tube through a screen plate. The second tube which has two internal electrodes, acts as the measuring chamber of the sensor. These two tubes form a manometer, and because of a pressure differential produced in the manometer, the sample pulp in the inner tube flows through the screen and accumulates in the measuring chamber. The amount of time required for the filtrate to reach from one level to another level is measured by the two electrodes and used as an index of freeness. After the filtrate contacts the upper electrode, the measuring cycle ends, and the chamber is cleaned using pressurized air and water, which back flush the filtrate through the screen and expel all the pulp from the inner tube.

Approximately 10-12 seconds later a new stock sample enters the inner tube and the cycle repeats. Depending on the furnish type and treatment, each measurement may take approximately 1-3 minutes. This sensor compensates for both temperature and consistency.

A summary of the specification of this sensor and other freeness sensors is given in Table 1. Shown in Figures 2 and 3 is Canadian Standard Freeness (CSF) from laboratory samples versus Innomatic sensor output (8) for bleached softwood, and hardwood, respectively.

II. TECO DRAINAC IIIB

TECO drainac IIIB (9), which is manufactured by the Thompson Equipment Company (TECO), is a more recent model of a series of Drainac sensors that were originally developed by the Bolton Emerson Inc. This sensor operates on the filtration principle, and employs a microprocessor that compensates for process variables such as pressure, consistency, temperature, and PH. The detector is mounted directly on the process pipe, and a predetermined differential pressure raises the stock into the detector tube. The measuring cycle of this sensor is as follows:

A. Start: The stock pressure is continuously measured at the detector tube by a transducer, and the air pressure is controlled to be a few psi (e.g., 5 psi) above the stock pressure. This pressure differential allows for the detector tube to be purged by air and water.

B. Intake/measure: After cleaning the measuring tube, the air pressure at the chamber is regulated to be a few psi below the process line pressure. Because of this pressure differential, the stock passes through a screen and rises in the measuring tube, then the time required for the filtrate to pass from the level of a lower electrode, and rises to the level of an upper electrode is measured as an index of freeness.

C. Exhaust/flush: A solenoid valve makes the detector pressure positive with respect to the process line pressure. Air and water are introduced into the system, and fibers and filtrates are pushed from the chamber and through the screen back to the stock line before the next measuring sequence.

Shown in Figure 4 is Canadian Standard Freeness (CSF) as measured from hand sample versus Drainac III B output (9) for a mixture of hardwood and softwood pulps.

III. KAJAANI PDA

The Kajaani pulp drainage analyzer (PDA) is an on-line sensor which operates on the measurement of the mass of the pulp pad collected on a filter (10). A sample is collected in the analyzer's chamber (Figure 5a) in which the measurement is performed in a condition isolated from the process line to avoid the effect of line pressure, consistency, and other process fluctuations. Up to four sampler devices can be used to extract a sample from various locations in the process pipe. The following are the measuring sequences of this sensor:

A. The pulp sample in the mixing chamber is diluted to a suitable consistency (e.g., 0.5-1.2%), and a fixed volume of it flows into the analyzer's camber (Figure 5b). After measuring the sample temperature, the stock is placed on a wire screen.

B. Water from the pulp pad formed on the screen wire is sucked by a vacuum, and after a predetermined suction time, the weight of the sample pad and the pressure difference over the pad are measured.

C. The measured values of pressure difference, pad weight, and pulp temperature are used to determine the pulp freeness.

D. The sampler and analyzer are flushed, and the measuring cycle is repeated.

Pressure difference (ΔP) at various times, and the set time at which ΔP is measured are shown in Figure 5c. Pulp sample consistency as measured by PDA versus those measured from lab samples is shown in Figure 5d (10).

IV. DRT-5200

DRT-5200 is an in line drainage analyzer (11) which provides two current output signals. One is a measurement of pulp freeness, which can be used for refiner control. The other signal corresponds to a temperature measurement in the mixing chamber. This measurement is used for temperature compensation of freeness. The sample is diluted in a mixing chamber to prevent flocculation and provide a better formation. The operation of this sensor is as follows:

A. Sampling phase: An air cylinder presses a piston into the process line, and a pulp sample is extracted in the mixing chamber in which diluted to a consistency of 0.3 to 0.5 percent.

B. Formation phase: The mixing chamber from the upper end is connected to a measuring glass through a screen, and from the lower ends is connected to an overflow pipe that forms a manometer with that pipe. Because of a pressure differential produced in the manometer, the stock is pushed from the mixing chamber to the screen, and a fiber pad is formed on the screen.

C. Measuring phase: Water drained through the fiber bed rises in the measuring glass, and the rising time is measured by two electrodes. The stock temperature in the chamber is measured, and the pulp drainage is determined from the measured time and the stock temperature.

D. Clean blowing phase: After the rising water in the measuring glass reached the upper electrode, compressed air blows the pulp/water mixture from the measuring glass, screen, and the mixing chamber into the overflow pipe. Then the mixture is completely discharged from the overflow pipe, and the cycle is repeated.

Shown in Figure 6 is the sensor output versus thermomechanical (TMP) pulp consistency (%Cs) for DRT 5200 and DRT 5090 (11).

V. KOEI

The KOEI freeness tester (12) is an on line sensor that can be installed in a pressurized or a non pressurized stock line. It dilutes the pulp sample to 0.1% consistency, and the manufacturer recommends connection of a signal from a consistency transmitter to this sensor for more accurate measurement of freeness. The following describe the measuring cycle of this sensor:

A. A fixed volume of water is entered in a measuring tube to be used for diluting the pulp sample to a consistency of 0.1%. Also, a fixed volume of pulp is removed from the process line or the stuff box.

B. Using compressed air, a uniform mixture of stock at 1% consistency is produced. After the right mixture is produced, air is allowed to escape from the mixture.

C. A constant air pressure is applied to the mixing tube to force the mixture through the screen. After a uniform pulp mat is formed, excess water is drained. Then the drain valves close, and water begins to rise in the measuring tube.

D. After a fixed time, the volume of water collected in the measuring tubes is measured by a bubbler tube. Also, the pressure differential across the screen is measured by a differential pressure transducer. Then the pulp freeness is determined from these measured values.

E. All valves open and the unit is thoroughly washed with a high velocity water nozzle. Then the cycle is repeated.
Shown in Table 1 is a summary of the specification for KOEI's freeness and the four other sensors discussed in this study.

Figure 7 shows KOEI's freeness tester's output versus Canadian Standard Freeness (CSF) from a hand sample for a long fiber bleached kraft pulp (LBKP), and Figure 8 shows the rate of consistency fluctuation versus KOEI's output (12) for the same pulp.

SUMMARY OF A PREVIOUS SENSOR EVALUATION STUDY

An evaluation of on-line drainage testers was conducted at the Institute of Paper Science and Technology (5) in which the sensitivity of Innomatic 63B-4, Drainac III, and BTG DRT 90 to process variables such as furnish type (a bleached Kraft long fiber, and a thermomechanical short fiber), freeness, consistency, temperature, PH, flow rate, and line pressure were determined. Samples were collected by dipping from a 2500-gallon tank for measurement of Canadian Standard Freeness (CSF), consistency, and PH. The mean value of three measurements for the CSF for each test condition was used as a reference. Experimental design of the study was based on Placket- Burman (P-B) which was chosen to minimize the number of tests needed to determine effects of the main variables and possible two-factor interaction among the variables. No compensation for temperature, consistency, or PH was used by any of the three sensors, and as expected, results of the study showed that all three sensors were sensitive to changes in temperature, consistency, and PH. Since the BTG sensor used city water to dilute the sample, its sensitivity to these variables was influenced by the city water. The sensors were also sensitive to stock flow rate and line pressure. These sensitivities were higher for the long fiber than the short fiber. The P-B experiment showed that for the long fiber, the interaction effect of refining/temperature on response of all three sensors was significant. Also, for Drainac and DRT-90 sensors, interaction of flow/pressure, and for the Innonmatic sensor, interaction of flow/temperature were significant.

IPST FLOW-LOOP

The Institute of Paper Science and Technology's Industrial Research Facility (IRF) is equipped with a flow-loop (Figure 9) which has the capability of pumping up to 600 gpm of 4% consistency pulp at a line pressure of 30 Psi. By adjusting the speed of the pump and the position of the throttle valve, other flow rates and pressure conditions can be accomplished.

Currently, we are using this facility in a study funded by the American Forest & Paper Product Association (AF&PA) to evaluate performance of commercial on-line consistency transmitters. By enhancing the capabilities of this flow loop (e.g., installation of a refiner), we will be able to install various freeness analyzers at the flow loop to evaluate their performance subjected to changes in process variables such as stock consistency and temperature.

ACKNOWLEDGMENTS

The authors sincerely acknowledge representatives of the sensor manufacturing companies for providing the test data, and technical information.

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12. Communication with Benco, Charlotte, NC.

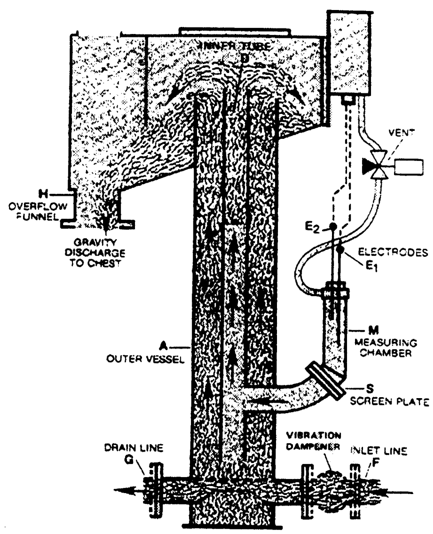


Figure 1. Measuring cycle of the Innomatic 63M-7 freeness analyzer.

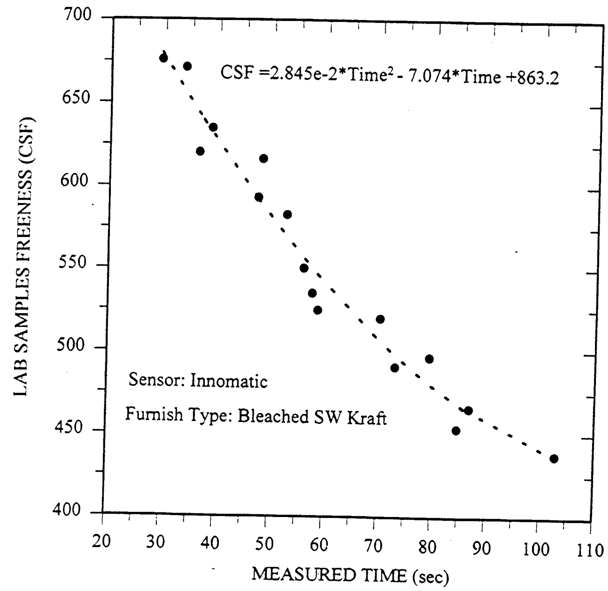


Figure 2. Canadian Standard Freeness (CSF) measured from laboratory samples versus the Innomatic sensor out put for a bleached softwood pulp.

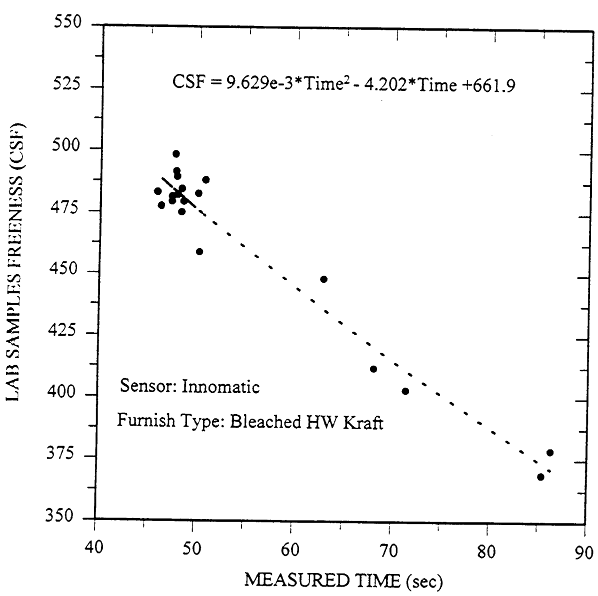


Figure 3. Canadian Standard Freeness (CSF) measured from laboratory samples versus the Innomatic sensor output for a bleached hardwood kraft pulp.

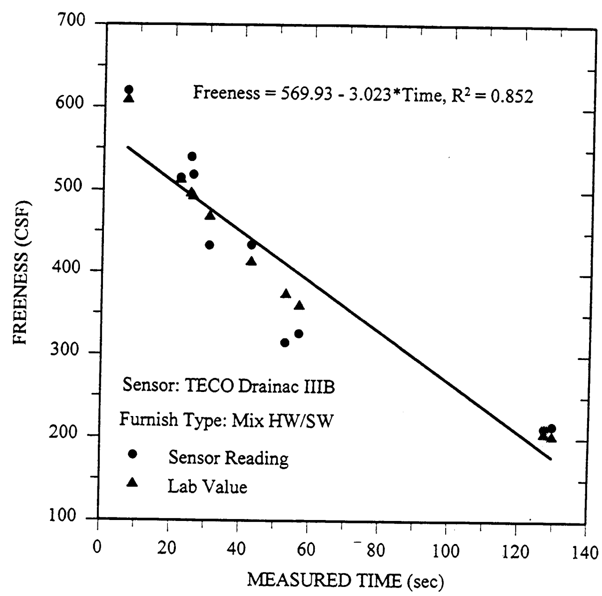


Figure 4. Canadian Standard Freeness (CSF) measured from laboratory samples versus the Drainac IIIB sensor output for a mixture of hardwood and softwood kraft pulps.

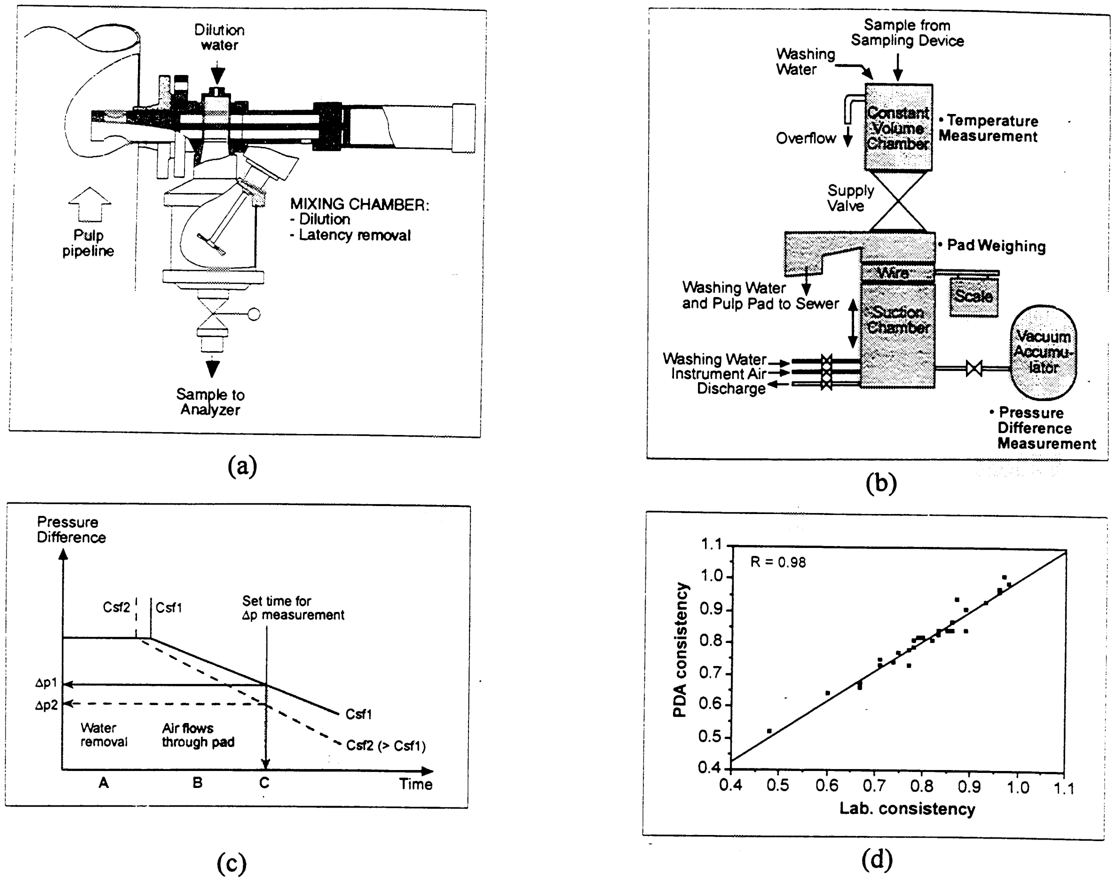


Figure 5. Valmet PDA sampler device (a), analyzer (b), pressure differential during suction (c), and the PDA consistency (Cs) versus hand sample Cs (d).

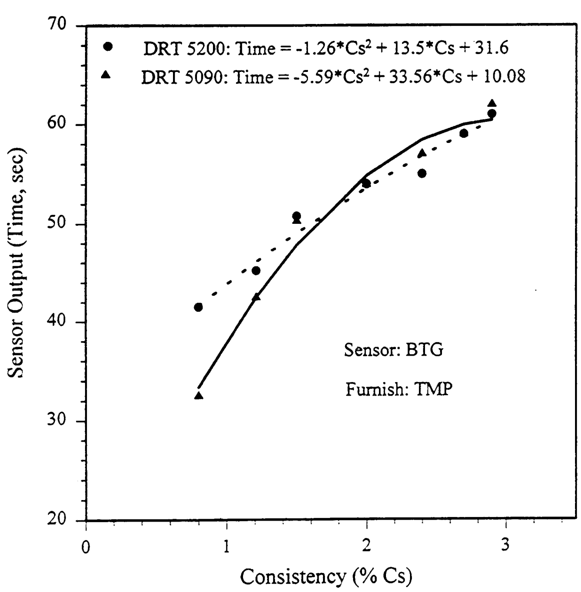


Figure 6. Sensor output (time) versus thermomechanical pulp consistency (%Cs) for two BTG freeness analyzers.

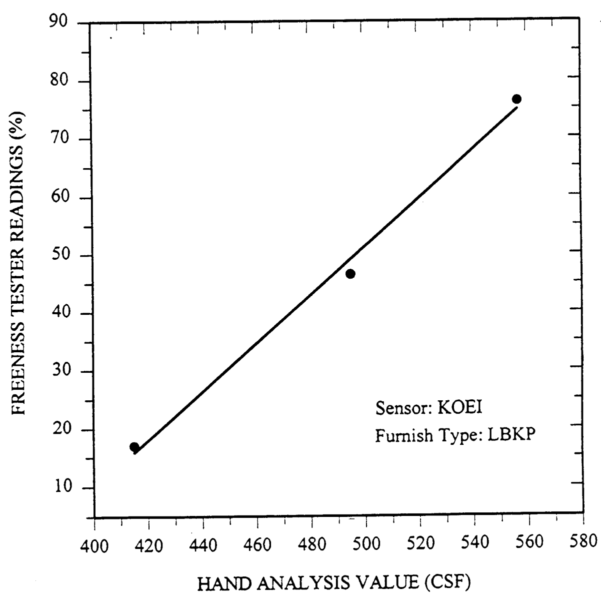
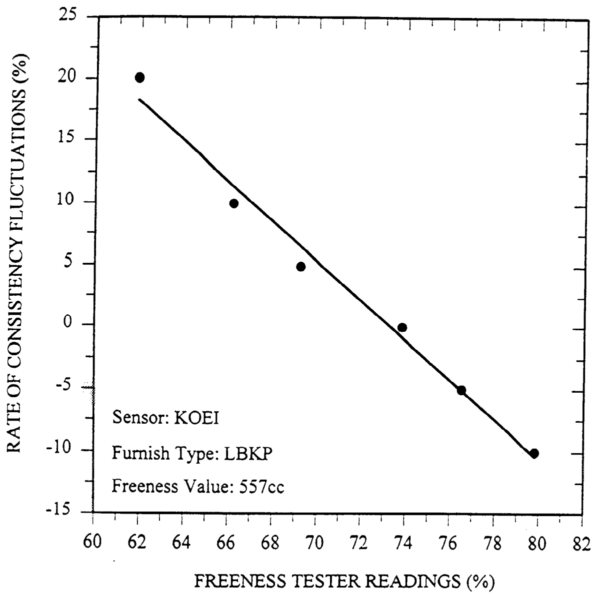


Figure 7. Output from the KOEI sensor versus Canadian Standard Freeness (CSF) measured from laboratory samples for a long-fiber bleached kraft pulp (LBKP).



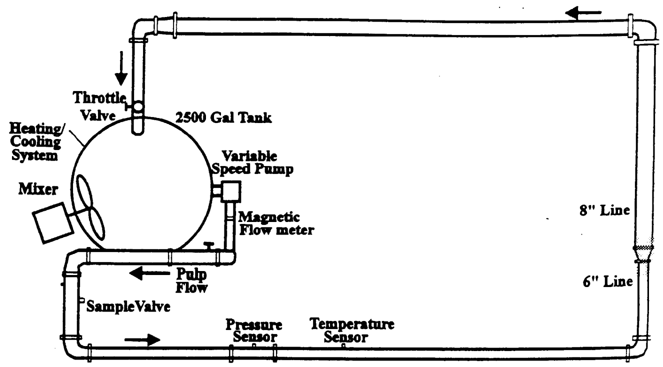


Figure 8. Consistency fluctuation versus the KOEI sensor output for a long-fiber bleached kraft pulp (LBKP).

Figure 9. Schematic diagram of the IPST flow loop. The freeness sensors can be installed at the horizontal sections of the flow loop.

Table 1- Specification of commercially available On-line Freeness Sensors.

SENSOR MODEL	ab INNOMATIC 63M-7	TECO Drainac IIIB	VALMET Kajaani PDA	KOEI	BTG DRT-5200
FREENESS RANGE (CSF)	40-700	0-800	20-750	0-800	10-775
QUANTITY MEASURED	Time (that filtrate travels from A to B)	Time	Mass (of fiber pad)	Volume (of filtrate)	Time
CONSISTENCY RANGE	0.2-6%	0.5-6%	0.5-6%	1-6%	1-6%
CS DURING MEASUREMENT	As sampled	As sampled	Diluted (0.5-1.2%)	Diluted (0.1%)	Diluted (0.3-0.5%)
MIN. STOCK LINE SIZE	3" Shunt	4"	6"	6"	6"
STOCK FLOW (ft/sec)	0.2 - 6%		1.6 (min)		1.6
PROCESS PRESS. (PSI)		10-90	145 (max)	85 (max)	145 (max)
WATER REQUIRED (PSI)	40-70	10 + P_{Line}	51-145	30-140	50-116
AIR REQUIRED (PSI)	60	10 + $_{Line}$	90-145	65-140	58-116
MAX. PROCESS TEMP. (°F)			226	175	203
MEASURING INTERVAL (SEC)	60-180	60-120	120-300	210-300	~120 (adjustable)
WEIGHT (LB)			55 (sampler)	200	