THE USE OF A FLOCCULATION SENSOR AS A PREDICTIVE TOOL FOR PAPER MACHINE RETENTION PROGRAM PERFORMANCE

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Application Statement

The findings presented in this paper suggest that the SLM/FBRM instrument can be used as a laboratory tool to predict machine retention program performance. In addition, SLM/FBRM can be used as an on-line sensor to monitor machine retention.

ABSTRACT

Microparticle containing retention programs were evaluated in an alkaline fine paper furnish by using a technique called Non-imaging Reflectance Scanning Laser Microscopy (SLM) or Focused Beam Reflectance Measurement (FBRM). SLM/FBRM was employed in both laboratory and paper machine studies. The relative efficiency and effectiveness of various microparticle programs as measured by SLM/FBRM in laboratory studies agreed with those derived during paper production. In addition, a SLM/FBRM unit was installed for the first time on two paper machines, XPM3 at Beloit Research Center, Rockton, IL, USA, and EuroFEX Experimental Paper Machine at STFI, Stockholm, Sweden. Changes in retention program chemistry and dose resulted in an immediate change in mean chord length, one of the available instrument outputs. Strong correlations were found between real-time mean chord length and machine retention data.

INTRODUCTION

Retention programs are widely used on modern paper machines to efficiently enhance the retention of fines and fillers and improve the removal of water from the papermaking stock. The ability of flocs produced by retention chemicals to resist degradation by shear and turbulence in

the paper machine headbox and forming elements is the main factor influencing machine retention *(1)*.

Although the shear conditions in a laboratory device are not the same as on a paper machine, bench-top procedures are commonly employed to select the optimal retention program prior to a machine trial *(2)*. It is generally accepted that such laboratory testing predicts the relative ranking of retention programs according to their effectiveness and/or efficiencies, within the dose range studied.

One of the devices traditionally employed in laboratory retention studies is the Britt Dynamic Drainage Jar (DDJ) *(3)*. The DDJ enables one to measure colloidal retention of solids independent of fiber mat formation. Non-imaging Reflectance Scanning Laser Microscopy (SLM), a technique recently introduced in papermaking applications *(1,4-7)*, also referred to as Focused Beam Reflectance Measurement (FBRM) *(8)*, allows in addition the derivation of information on floc degradation kinetics of papermaking furnishes treated with chemical retention aids. Based on correlations found between SLM/FBRM output and Britt Dynamic Drainage Jar (DDJ) measurements of fines retention, it was concluded that the SLM/FBRM technique can be employed similarly to the DDJ in laboratory retention program evaluations *(1, 4)*.

One of the goals of the present studies was to answer the question as to whether the SLM/FBRM instrument can be used as a predictive tool for retention program performance on a paper machine. For this purpose, the efficiency and effectiveness of various microparticle programs in a fine paper furnish was tested both in the laboratory by using the SLM/FBRM instrument, and on a paper machine, Beloit Corporation's Experimental Pilot Paper Machine Number 3 (XPM3), at Beloit Research Center, Rockton, IL, USA.

The second goal of this work was to establish the applicability of SLM/FBRM for on-line evaluation, optimization, and control of wet end chemicals. In this paper, we present for the first time SLM/FBRM data collected by using an on-line instrument unit. The on-line SLM/FBRM sensor was installed on two pilot paper machines, Beloit XPM3, and the EuroFEX Experimental Paper Machine at STFI, Stockholm, Sweden. In both trials the sensor was used to measure the flocculation performance of microparticle programs in an alkaline fine paper furnish. Based on these studies, recommendations are given for the use of SLM/FBRM for the on-line characterization of papermaking systems and optimization of chemical treatment programs.

EXPERIMENTAL

Materials

Furnish composition. Once-dried bleached kraft softwood (SWK) and hardwood (HWK) pulps were slurried and refined separately in a Beloit Double-Disc refiner. SWK (Albacel) and HWK (Natchez) used in the Beloit furnish preparation were refined to a Canadian Standard Freeness of 400 mL and 350 mL, respectively. Both pulps were refined to 25°SR in the case of the STFI furnish. For Beloit and STFI furnishes, HWK and SWK were blended at a 60/40 ratio. Filler was added in an amount such that the solids of the final furnishes were composed of 70 % by weight

of total fiber and 30 % by weight of filler. The filler was ground calcium carbonate (Omyafil for the Beloit furnish and Hydrocarb HO in the case of STFI furnish, both from Omya). Omyafil is supplied as a dry solid containing an anionic dispersant while Hydrocarb HO is supplied as an anionically dispersed slurry.

Chemical Additives. The retention programs used in laboratory and pilot paper machine studies consisted of combinations of cationic starch/flocculant/microparticles. The cationic starch used in laboratory and pilot paper machine studies with Beloit furnish was STA-LOK® 400 from A.E. Staley. This is a cationic potato starch with a degree of substitution of 0.03. The starch used in the EuroFEX pilot paper machine trial was HI-CAT® 1164 from Roquette. HI-CAT® 1164 is a cationic potato starch having a degree of substitution of 0.045. Both types of starch are used extensively as wet end additives. In all the studies the cationic flocculant was a 10 mol% copolymer of acrylamide and trimethyl-(3-methacrylamido-propyl)-ammonium chloride.

Microparticles consisted of both experimental and commercial materials. A commercial colloidal silica, Nalco® 8671, is represented below as MP1. MP2 is a proprietary colloidal silica based material. The MP3 microparticle was a sodium montmorillonite (SCPX1475), obtained from Southern Clay Products, Inc. The microparticles MP4 and MP5 are both proprietary materials. Finally, MP6 is a new patent pending nanosize borosilicate *(9)*.

Equipment and Procedures

SLM/FBRM. Measurement of the chord length distribution of furnishes was carried out by using two types of commercially available SLM/FBRM instruments (M100F for the laboratory experiments, and 500P for the on-line studies, Lasentec Corporation, Redmond, WA, USA). The SLM/FBRM instrument operates by scanning a focused laser beam (beam spot dimension = 2 μm x 0.8 μm with a light intensity at the focal point of 2 x 10^{10} W/m^2) at fixed speed across particles in suspension, as illustrated in **Figure 1**. The backscattered light from the particles is transmitted via fiber optics to an avalanche photodiode detector *(10)*. The resulting number of individual pulses exceeding a predetermined threshold level is counted and binned according to the pulse duration. Since the scanning velocity of the laser is known (i.e., fixed at 2 m/s), the time taken for the laser to scan across a particle provides a characteristic measure of the particle geometry known as the "chord length". Typically, thousands of chord length measurements are collected per second, producing a chord length distribution divided logarithmically across 38 bins covering the range 0.8-1000 microns. The chord length distribution data can be used to calculate various statistical parameters, such as mean, median, skewness, kurtosis, etc. Such chord length statistics provide a means of quantifying particle population and dimension information for a wide range of suspended particle systems.

The bench-top and pilot paper machine experiments described in this paper used *mean chord length* (*MCL*) data as the primary sensor output. The *MCL* is defined by the following equation:

$$\textit{Mean chord length}, \quad MCL = \frac{\sum_{i=1}^{38} (Y_i * M_i)}{\sum_{i=1}^{38} Y_i}$$

where Y_i and M_i are the particle chord counts and chord length (in microns), respectively, for each of the 38 channels in the chord length distribution.

The instrument settings used in the laboratory experiments were: (1) a measurement duration time of 3.2 s; (2) no signal averaging between data points; (3) no data smoothing/averaging between channels; and (4) the laser focal position was fixed at -20 µm, relative to the probe window/fluid interface. Similar settings were used during the on-line studies except for the measurement duration time that was changed to 30 s.

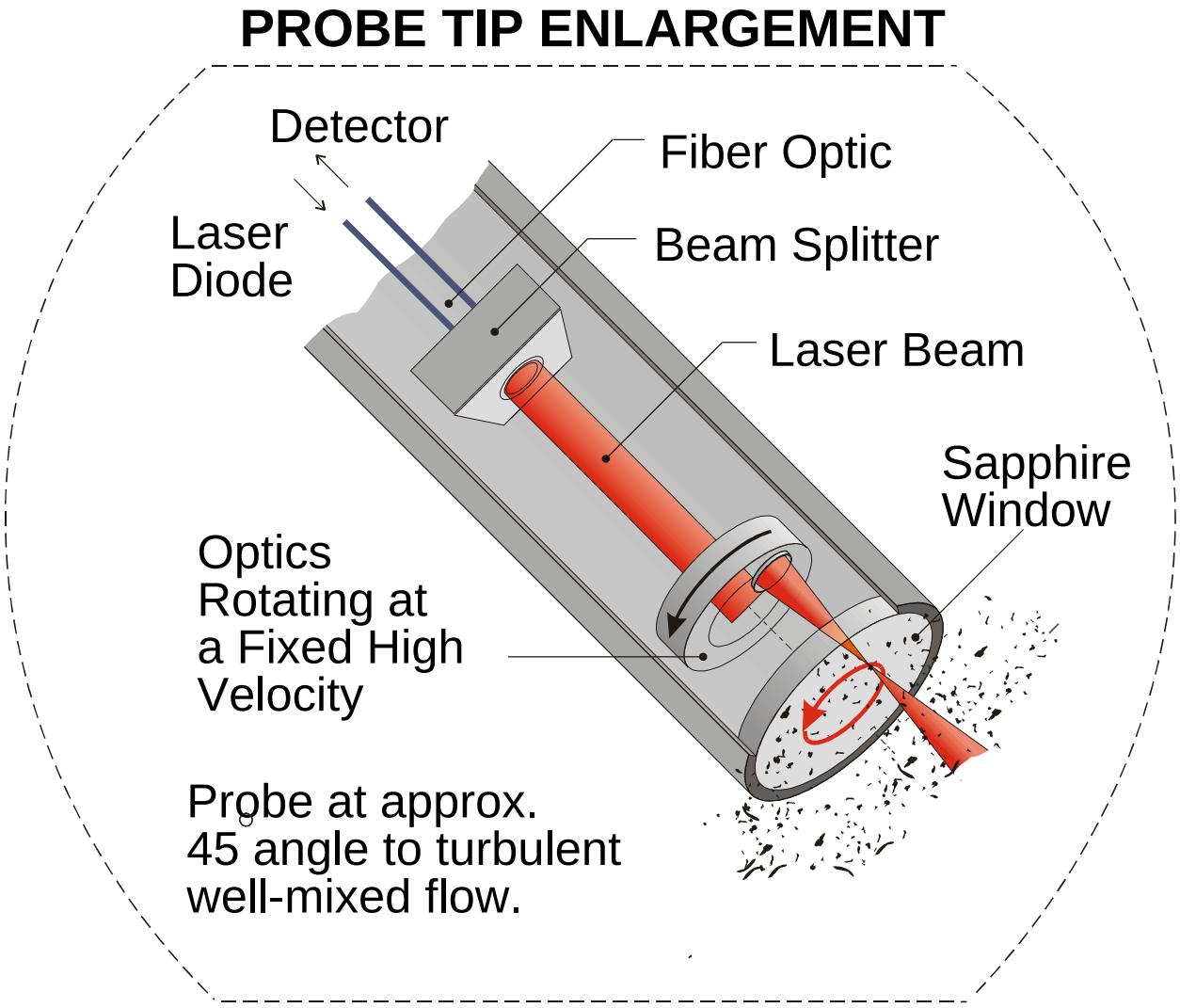

Figure 1. Schematic representation of the SLM/FBRM probe.

In laboratory experiments, 300 mL of fine paper furnish was employed in each experiment. The furnish contained in a 500 mL beaker was stirred at 750 rpm, and chemical additives were added according to the following time sequence,

t = 0	Start
t = 30 s	Add starch
t = 45 s	Add cationic flocculant
t = 90 s	Add microparticles
t = 135 s	Stop recording data

In the pilot paper machine trials, the SLM/FBRM probe was inserted into a dedicated PVC side-stream piping system, with the probe's longitudinal centerline angled 45±5 degrees to the sampling pipe's vertical axis such that the probe's sapphire window faced the oncoming furnish flow. The probe's insertion point was approximately four pipe diameters downstream from a 90-degree elbow, thus conforming to standard installation recommendations from the manufacturer. The center of the probe's sapphire window was located as close as possible to the sampling pipe's centerline.

For the Beloit XPM3 trial, thin stock was sampled approximately 1.5 m prior to the headbox tapered header, through 2.5 cm I.D. hose, with constant sampling flow of 29.0 L/min. The sampling hose was connected to the dedicated PVC piping system, with sample discharge diverted back to the off-machine white water silo. For the STFI EuroFEX trial, thin stock was sampled approximately 1.0 m prior to a three-way approach piping split used to feed each of three plies in a stratified headbox. This sampling point was a total distance from the headbox tapered header of approximately 2.0 m. The EuroFEX sample flowed through a 2.0 cm I.D. hose at a constant 24.0 L/min; the sample discharge was returned to the white water silo.

Pilot Paper Machines

Beloit Research Center XPM3. Beloit's XPM3 can be configured as conventional Fourdrinier, hybrid top-wire former, or as a horizontal gap/roll/blade former. The horizontal gap/roll/blade former configuration was used in the trial described in this paper. XPM3 operating conditions are shown in **Table I**. A schematic of the XPM3 approach system, including chemical addition and FBRM sampling points, is shown in **Figure 2**. Based on previous trials performed on Beloit's Experimental Pilot Paper Machine Number 2 (XPM2), it was assumed that fifteen minutes would be required to achieve system equilibrium following each retention program change. Since XPM3 was not equipped with on-line consistency sensors for detection of system equilibrium, it was decided that twenty minutes run time should be allowed for each experimental condition, with an additional five-minute period to be used for sample collection. The XPM3 water system is very open (with all overflows diverted to sewer), and without disk filter fines recovery. The XPM3 configuration during this trial allowed for wet sheet sampling at the exit of the press section. The wet sheet samples were dried on a separate single-drum steam dryer to obtain the final paper samples. All thin stock and sheet samples were collected during the system equilibrium period. The results presented in this paper were collected over four day of XPM3 operation.

STFI EuroFEX Pilot Paper Machine. STFI's EuroFEX offers three distinct forming section configurations: Fourdrinier, gap/blade, and gap/roll/blade formers. Here also, the gap/roll/blade former configuration was used during the trial described in this paper. STFI's EuroFEX paper machine was described earlier in greater detail *(11)*. Other EuroFEX operating conditions are

given in Table I. A schematic of the EuroFEX short circulation system, with chemical addition and SLM/FBRM sampling points, is shown in **Figure 3**. The EuroFEX has a closed white water system, and small (5 m^3) white water silo. A proprietary STFI on-line consistency sensor installed on the EuroFEX provides real-time assessment of system conditions; this data was used to detect machine equilibrium and establish sampling intervals during the trials. Similar to Beloit's XPM3, the EuroFEX configuration allowed for wet sheet sampling at the exit of the press section. The paper was collected after the third press and dried under restraint in both machine and cross-direction on an electrically heated drum-dryer. All thin stock and sheet samples were collected after the EuroFEX had reached equilibrium. The results presented in this paper were collected over four days of EuroFEX operation.

Table I. Paper Machine Operating Conditions

	EuroFEX	**Beloit XPM No. 3**
Forming unit	Vertical gap/roll/blade former	Horizontal Bel Baie RBC Former
Headbox	Valmet HTB-3	6-channel Concept-IV MH
Wire tension	6.0 KN/m	
Machine speed	900 m/min	3400fpm(≈1100m/min)
Slice opening	14 mm	
Jet/Wire speed ratio	0.97	1.06
Press loads	60, 500, and 700 KN	300, 400, 500, and 600 pli

RESULTS AND DISCUSSION

The laboratory retention performance of various microparticle programs was evaluated in a fine paper furnish by using the SLM/FBRM technique. The microparticle programs consisted of cationic starch, flocculant, and microparticle combinations. The dose of the starch and flocculant, a cationic polyacrylamide, was kept constant, whereas microparticles were added at three different dose levels. The six-microparticle types used in these experiments, varied in composition and chemistry.

A typical mean chord length (*MCL*) trace from a SLM/FBRM laboratory experiment is shown in **Figure 4**. As seen in Figure 4, the addition of each component - starch, flocculant, and microparticle - produces an increase in the *MCL*, as a result of particle aggregation, followed by a shear-induced *MCL* decay *(1,4)*. For the purposes of this study, the net *MCL* increase after microparticle addition (furnish re-flocculation) was used to monitor the relative performance of tested microparticles. The net *MCL* change, ΔMCL, was determined as the difference between the *MCL* value just prior to microparticle addition and the *MCL* maximum after microparticle addition. ΔMCL data are plotted as a function of the microparticle type and dose in **Figure 5**.

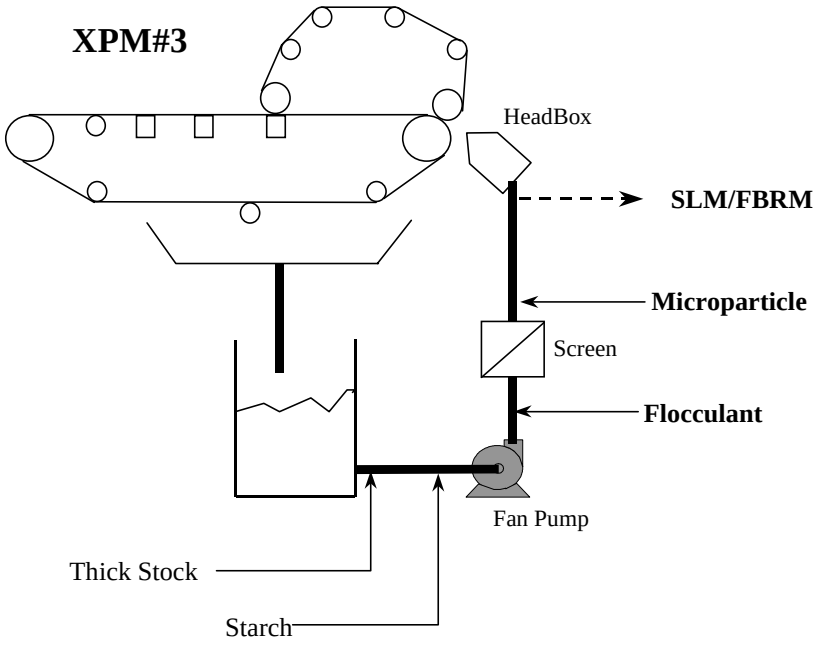

Figure 2. **Schematic diagram of XPM3 pilot paper machine approach piping indicating addition points of the retention program and installation of the SLM/FBRM probe.**

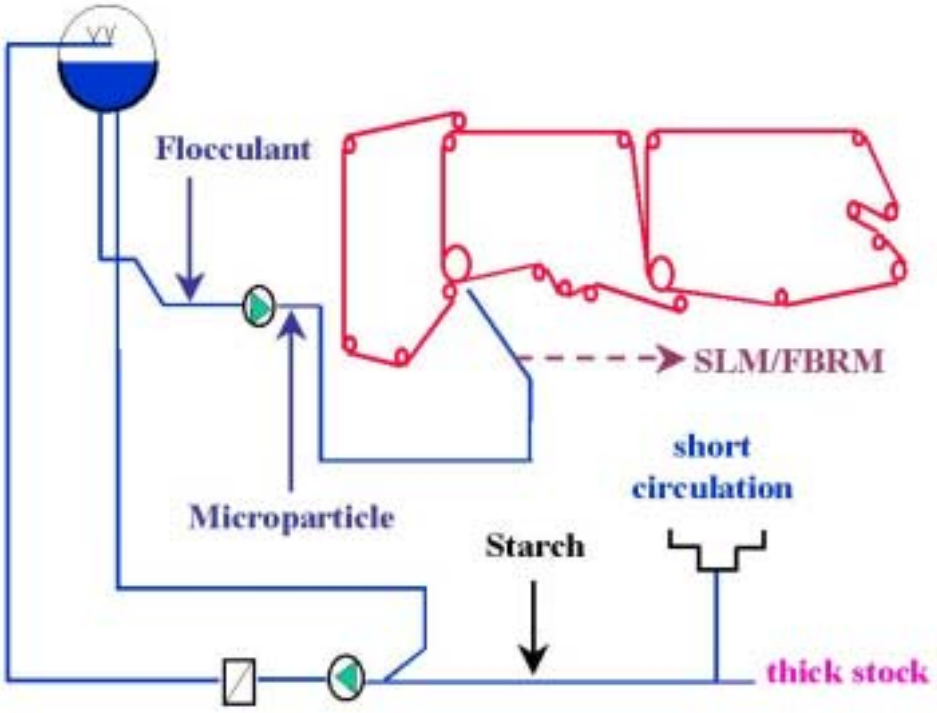

Figure 3. **Schematic diagram of the short circulation of EuroFEX experimental paper machine indicating chemical addition and SLM/FBRM unit installation points.**

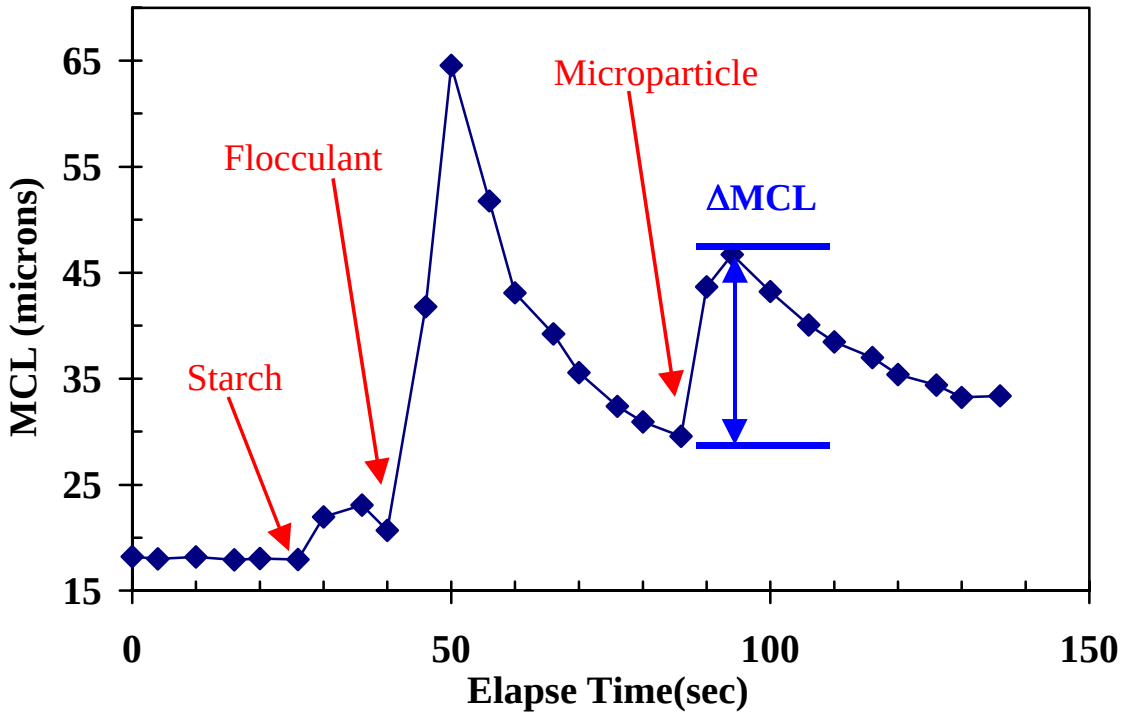

Figure 4. **The time-dependence of the mean chord length for the cationic starch/flocculant/ microparticle retention program.**

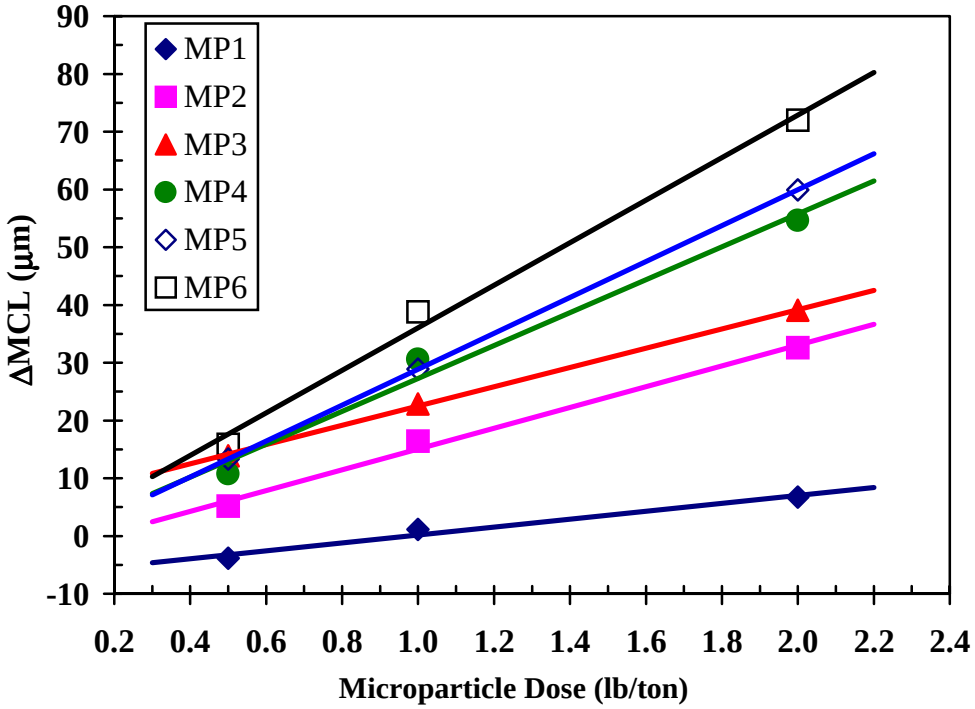

Figure 5. **The microparticle-dose dependence of mean chord length data as measured in laboratory experiments.**

Microparticle dose-dependent data obtained from SLM/FBRM experiments (Figure 5) were best fitted by using linear functions. Slopes, intercepts, and R^2-adjusted values of the fitted equations are listed in **Table II**. Comparison of the slope values allows ranking of the retention programs containing the various microparticles according to their efficiencies as,

$$MP1 < MP2 < MP3 < MP4 < MP5 < MP6$$

Table II. Laboratory Responses on Beloit Furnish

	Slope	Intercept	R^2-adj
MP1	6.86	- 6.68	0.953
MP2	17.97	- 2.91	0.985
MP3	16.69	5.81	0.999
MP4	28.48	- 1.21	0.964
MP5	31.08	- 2.22	1.000
MP6	36.82	-0.745	0.986

The relative effectiveness of the test materials exhibits the same order as above within the range studied. In order to determine if the same order in performance would hold for identical microparticle programs applied on a paper machine, a four-day pilot paper machine trial was run on Beloit XPM3 Pilot Paper Machine, using the same furnish and microparticle programs as in the laboratory studies. Target XPM3 sheet properties for the trial are listed in **Table III**. Another goal was to evaluate SLM/FBRM instrument as on-line retention sensor. Therefore, a SLM/FBRM unit was installed on machine during the same trial, to monitor in real-time the fluctuations of *MCL* due to changes in microparticle program and dose.

Table III. Target Paper Characteristics

	STFI EuroFEX	Beloit XPM No. 3
Basis Weight(gsm)	74.4	60
Ash Content(%)	30 %	18 %
Thick Stock Ash Content(%)	30 %	30 %

First Pass Retention (*FPR*) and First Pass Ash Retention (*FPAR*) on machine were determined from consistency and ash content measurements of headbox and white water samples by using the following equations,

$$FPR,\% \ = 100 \times \frac{HB_c - WW_c}{HB_c} \qquad [1]$$

$$FPAR,\% = 100 \times \frac{(HB_c \times HB_a) - (WW_c \times WW_a)}{(HB_c \times HB_a)} \quad [2]$$

where, HB_c and WW_c are the headbox and white water consistencies, and HB_a and WW_a are the headbox and white water ash levels.

In addition, retention was computed as the ratio of the ash content of the paper leaving the couch roll to the ash content of the furnish in the headbox,

$$MAR,\% = 100 \times \frac{\text{Sheet Ash}}{HB_a} \quad [3]$$

In **Figure 6**, Machine Ash Retention or *MAR* data, calculated according to equation [3] are plotted as a function of microparticle dose. *MAR* data for the six-microparticle programs fit linear functions and the correspondent slopes, intercepts, and R^2-adjusted values of the fitted equations are reported in **Table IV**. The relative order of microparticle efficiency derived by comparing slope values is,

MP3 < MP1 < MP2 < MP4 < MP5 < MP6

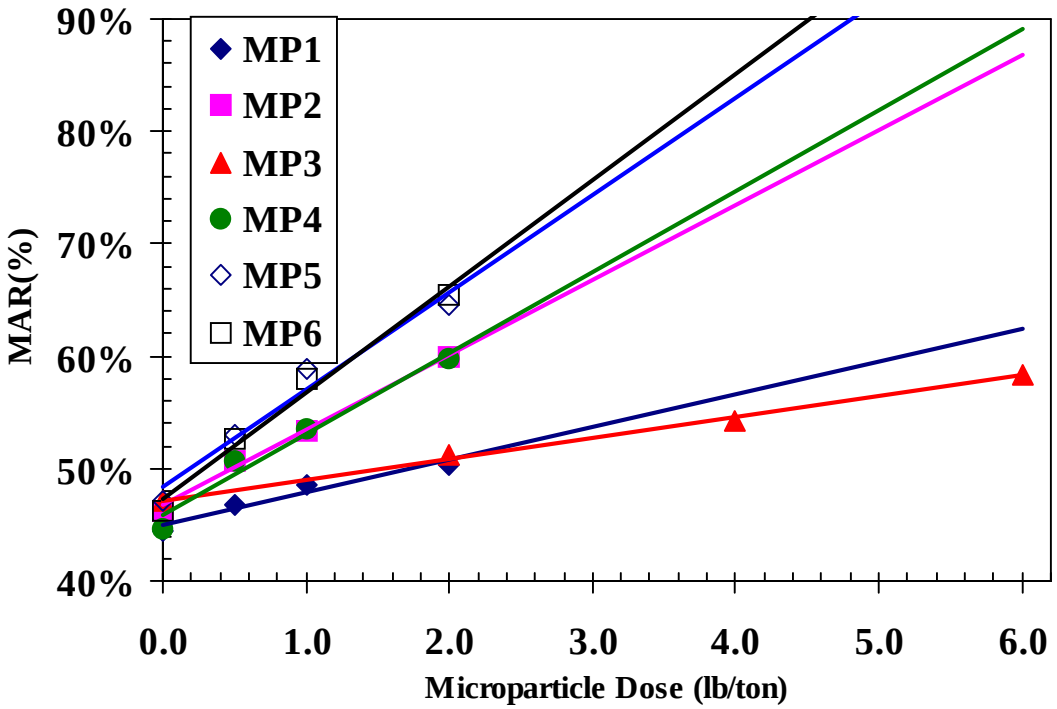

Figure 6. The microparticle-dose dependence of XPM3 machine ash retention (*MAR*) data derived calculated according to equation [3].

As above, the effectiveness follows the same order within the experimental region studied. Here then, the overall agreement between laboratory and machine retention data is quite good, except for the relative position of MP3. The difference in relative performance of MP3 in laboratory and machine studies is most likely due to differences in microparticle sample preparation. It is known that the performance of sodium montmorillonite (MP3) is influenced by the degree of shear, time, and temperature during the product dispersion step *(12)*. The bentonite used in laboratory studies was swelled with deionized water for 2 weeks. In contrast, the bentonite slurry was prepared approximately 72 hours prior to use.

Table IV. Beloit XPM#3 Responses

	MCL			*MAR*, %		
	Slope	**Intercept**	**R^2-adj**	**Slope**	**Intercept**	**R^2-adj**
MP1	0.548	11.46	0.838	2.91	44.94	0.925
MP2	1.902	11.84	0.967	6.67	46.70	0.990
MP3	0.357	11.64	0.987	1.85	47.17	0.995
MP4	1.826	12.0	1.000	7.21	45.87	0.954
MP5	2.600	11.94	0.966	8.68	48.30	0.943
MP6	3.204	11.15	0.948	9.45	47.29	0.973

Graphs were also generated by plotting *FPR* and *FPAR* values calculated according to equations [1] and [2], respectively, as a function of microparticle type and dose. These curves did not exhibit smooth dose dependence as observed for the *MAR* curves. This is most likely the result of inconsistencies in obtaining samples or erroneous consistency measurements. The same group of machine operators collected wet end and sheet samples, and measured their ash content for the determination of *MAR*. Conversely, *FPR*/*FPAR* data were determined from consistency measurements performed by a variety of operators. Others were responsible for collecting these samples.

During the same machine trial, a SLM/FBRM unit was installed in the furnish approach piping to determine the applicability of the instrument as an on-line retention sensor. The *MCL* data measured by the SLM/FBRM is plotted as a function of microparticle dose in **Figure 7**. As in the laboratory studies, the response as a function of microparticle dose was linear and hence the relative order of microparticle efficiency is derived by comparison of the derived linear slopes. This is accomplished in the same manner as the relative order derived from *MAR* data (Table IV and **Figure 8**).

As shown in **Figure 9**, a strong correlation was found between *MCL* data measured by SLM/FBRM during production and the *MAR* data. However, *MCL* data did not correlate to *FPR* or *FPAR* (R^2-adjusted = 0.4744 and 0.2752, respectively), indicating one more time the unreliability of *FPR*/*FPAR* data.

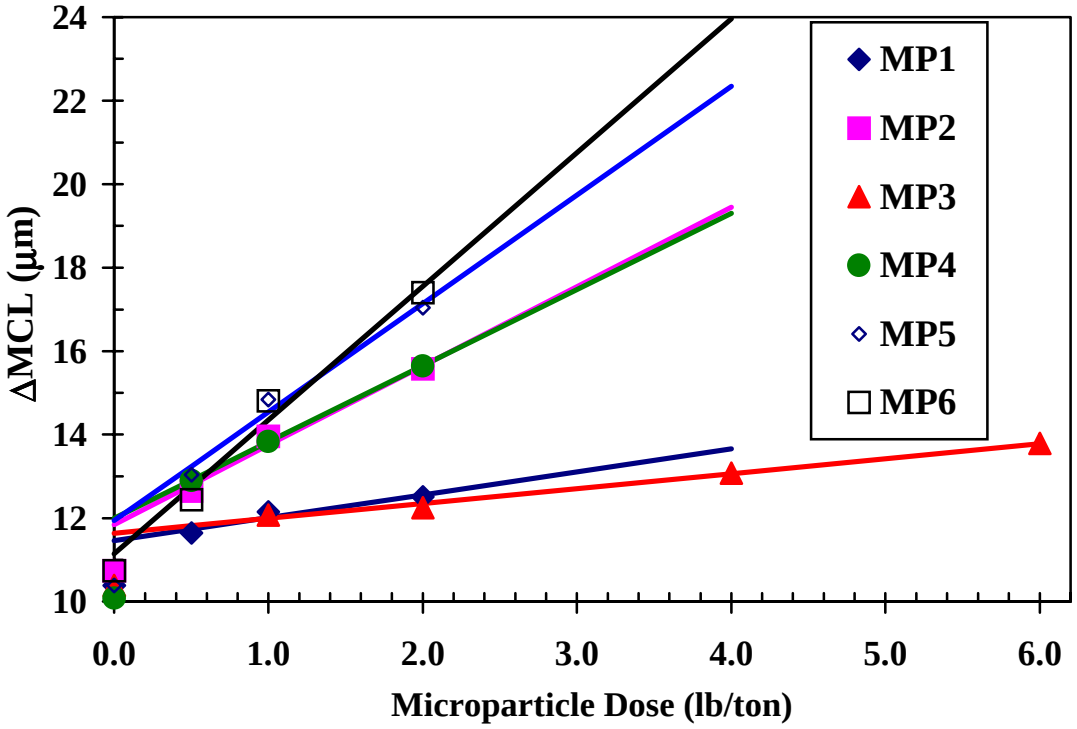

Figure 7. **The microparticle-dose dependence of mean chord length data measured by SLM/FBRM installed on the XPM3 pilot paper machine.**

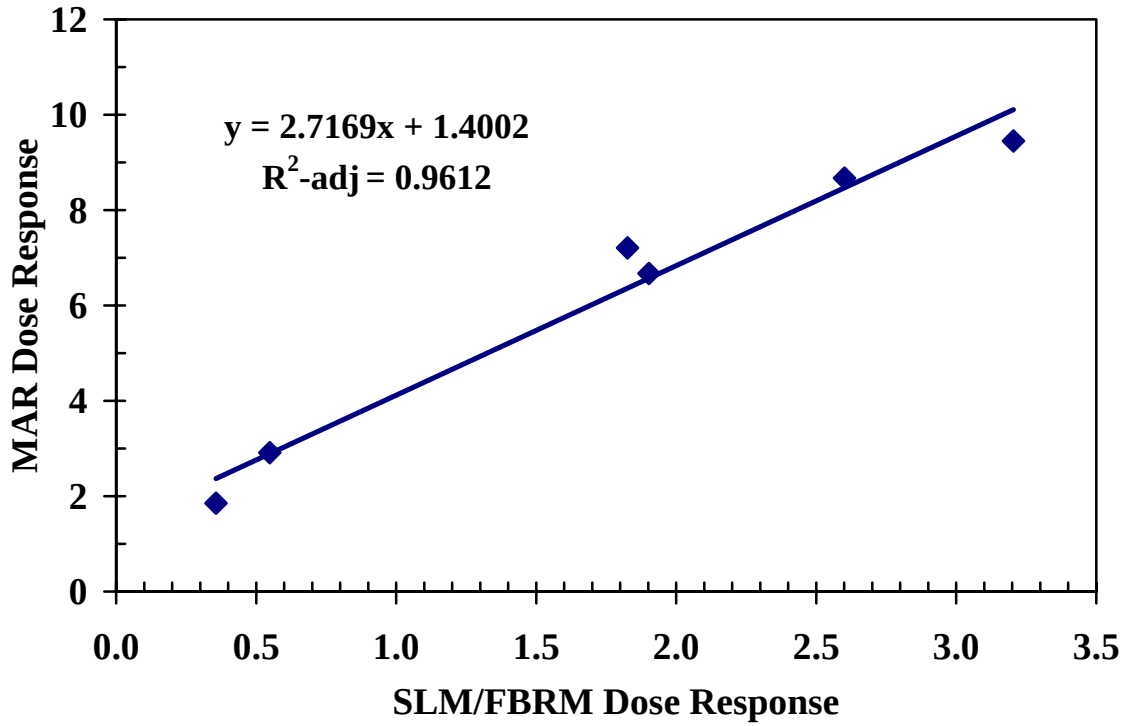

Figure 8. **Correlation of *MCL* and *MAR* dose response data for the six examined microparticles. Dose response data were derived by fitting *MCL* and *MAR* data to linear functions. The slopes derived from the fitting equations (Table IV) were used to generate the plot in Figure 8.**

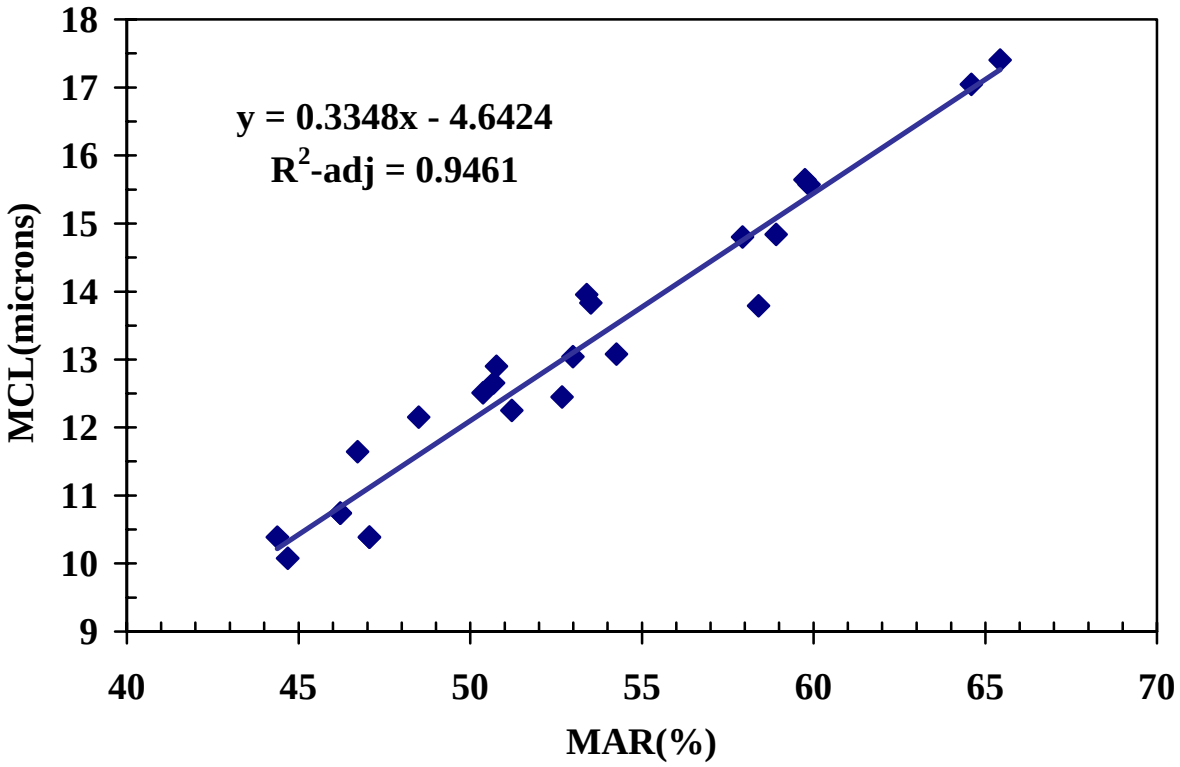

Figure 9. Correlation between mean chord length data collected by SLM/FBRM installed on the XPM3 pilot paper machine and *MAR* values calculated according to equation [3].

The evaluation of the SLM/FBRM instrument as a on-line sensor to measure retention was completed by installing a SLM/FBRM on a second pilot paper machine, the EuroFEX Experimental Paper Machine at STFI, Stockholm, Sweden. Retention programs evaluated in this trial were similar to the Beloit's ones and consisted of combinations of cationic starch, flocculant, and microparticles. The starch and flocculant dose was kept constant, whereas the microparticle dose was varied. The furnish was also in this case a fine paper furnish. Target sheet properties for the trial are listed in Table III. The EuroFEX machine is equipped with a sensor measuring on-line headbox and white water total and fiber consistencies. These data were used to derive *FPR* and *FPAR* values according to equations [1] and [2]. **Figure 10** shows the linear correlation obtained between *MCL* data and *FPAR* data determined using sensor-derived consistencies. Similarly, a good correlation was found between *MCL* and *FPR* data (R^2-adjusted = 0.9469). *MCL* data correlated as well with *MAR* data (**Figure 11**). *MAR* data used to generate the correlation in Figure 11, were calculated from manually derived ash consistencies.

Finally, **Figure 12** shows the *MCL* real-time data as measured by the SLM/FBRM unit during one of the day's operation of XPM3 and EuroFEX pilot paper machines. As can be seen in both cases, the change in dose or program was accompanied by an immediate change in *MCL*. In the case of the EuroFEX machine, the *MCL* trace obtained after a change in retention chemistry or dose more quickly reached a stable condition, i.e. the time to reach equilibrium was shorter, than in the case of the XPM3 machine. This is most likely the result of differences in machine configuration and first pass retention levels.

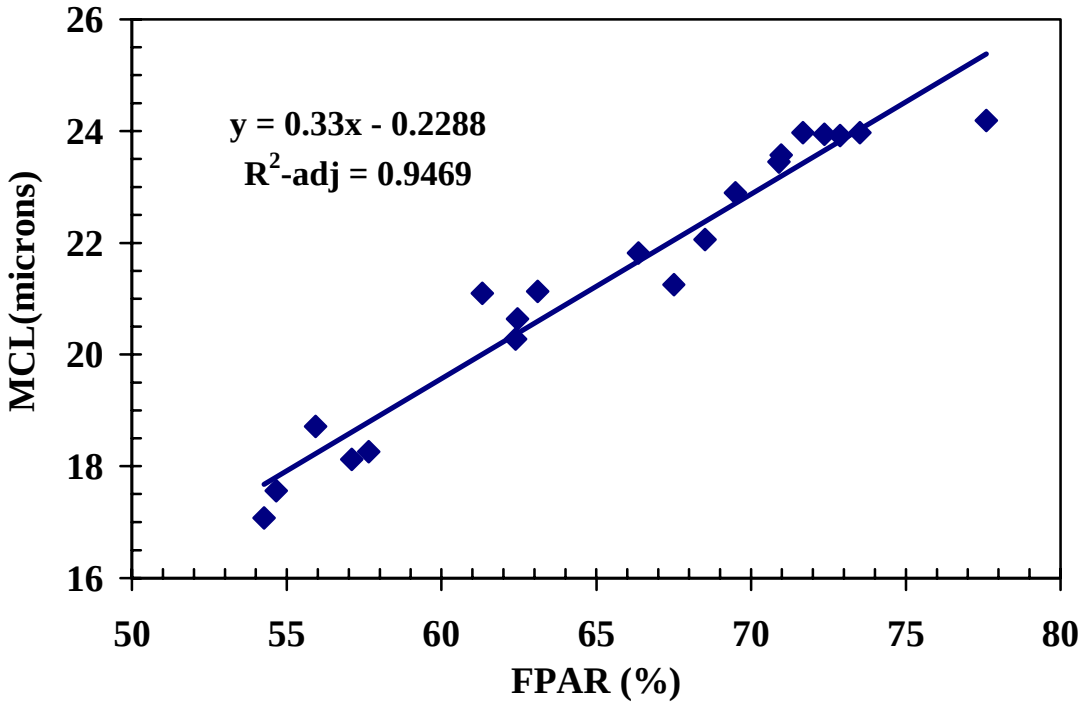

Figure 10. **Correlation between mean chord length data collected by SLM/FBRM installed on the EuroFEX pilot paper machine and *FPAR* values calculated according to equation [2].**

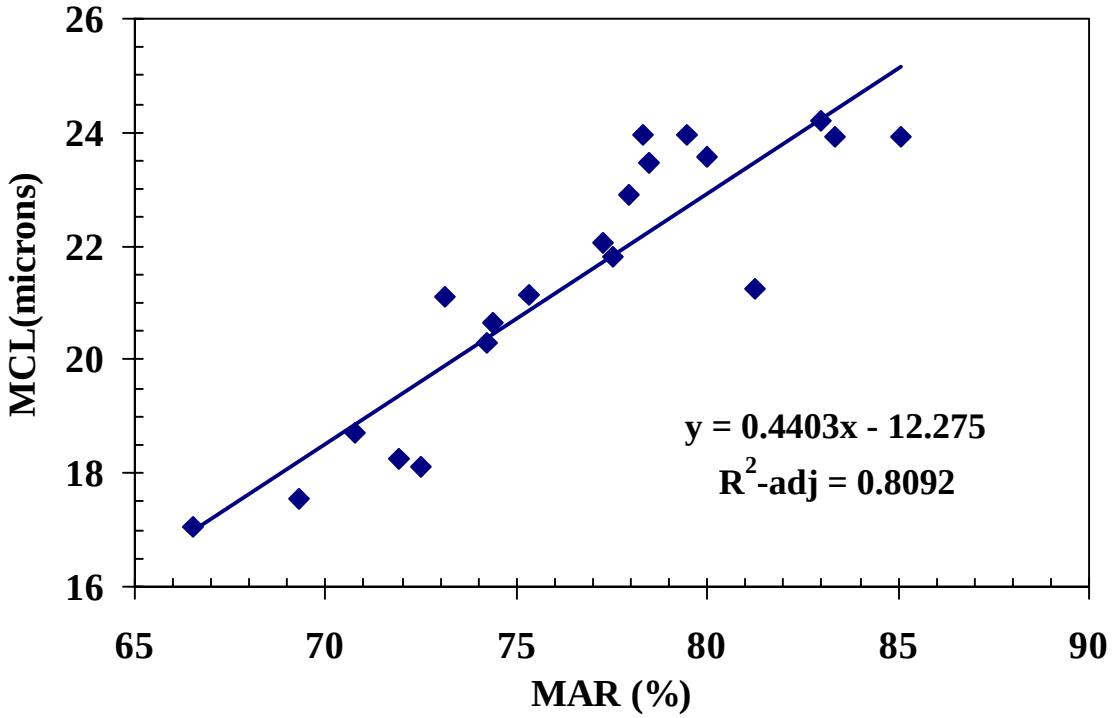

Figure 11. **Correlation between mean chord length data collected by SLM/FBRM installed on the EuroFEX pilot paper machine and *MAR* values calculated according to equation [3].**

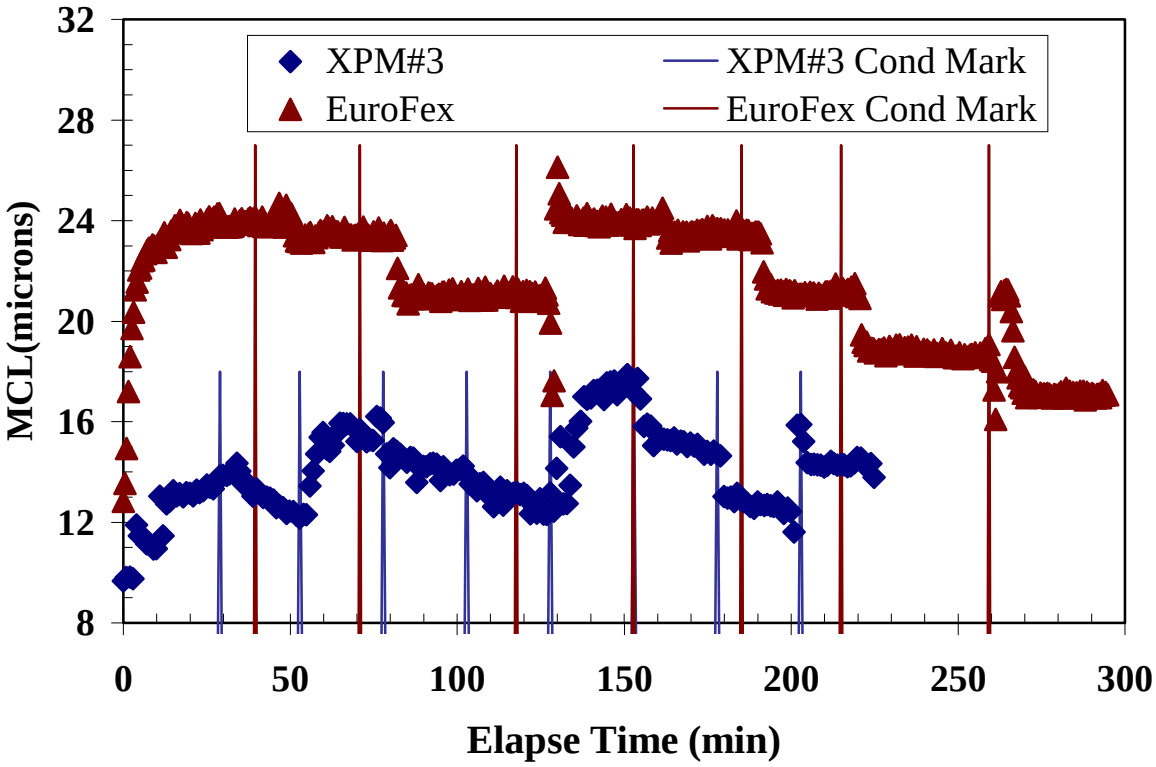

Figure 12. Comparison of the SLM/FBRM mean chord length traces obtained for the XPM3 and EuroFEX pilot paper machines. The marks on the figure indicate changes in retention chemistry or dose.

CONCLUSIONS

The work presented in this paper has demonstrated that the SLM/FBRM technique can be used both in the laboratory and on machine to monitor retention program performance. A similar order in relative performance was obtained for a series of microparticle programs when tested in an alkaline fine paper furnish in the laboratory, by using the SLM/FBRM instrument, and on machine, the Beloit XPM3 pilot paper machine.

In addition, this study has demonstrated the utility of on-line monitoring of the furnish via SLM/FBRM. An on-line instrument version was installed on both XPM3 and EuroFEX pilot paper machines. The two machine trials were run by keeping constant the operating conditions and furnish type. Under these conditions, monitoring of the headbox furnish flocculation state provided information on the chemical program efficiency. On the other hand, several changes in furnish composition occur in the wet end of production paper machines due to variations in raw materials, refinement level, or headbox filler/fiber ratios. In order to discriminate changes in the flocculation state of the furnish due to retention additives from changes due to other wet end fluctuations, the use of two SLM probes, one before and one after retention chemical addition, may be required for the optimization of the wet end and control of the additive dose.

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