# Pulping and TCF Bleaching of Canadian Wheat Straw and Oat Straw

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## ABSTRACT

The Canadian Prairies grow a large amount of cereal crops, and the crop residues are only partially used for various purposes such as soil conditioning and livestock bedding and feed. This study evaluated wheat straw and oat straw as raw materials for papermaking pulp production. Trials were carried out on 100% wheat straw, 100% oat straw and a 50/50 mix of the straws. Pulping was done using the soda-AQ process followed by TCF bleaching using a QPpZ sequence for a target brightness of greater than 85% ISO. The bleached straw pulps were tested for physical properties and compared to the physical properties of bleached eucalyptus kraft pulp (BEK). At the same freeness, the straw pulps had low tear index as compared to BEK but had similar or higher tensile index and significantly higher burst index. The bleached straw pulps were acceptable for papermaking.

*Keywords: Avena sativa, oat straw, Triticum sativum, wheat straw, pulping, bleaching, pulp properties*

## INTRODUCTION

Canada has about 36.4 million hectares (Mha) of crop lands available for agriculture. More than 85%, or about 34 Mha, are located on the Canadian Prairies in the provinces of Alberta, Saskatchewan and Manitoba. Cereal crops dominate the seeded area, followed by oilseeds and pulse crops. Most crop residues are left on the field after grain harvesting; however, some residues are used for livestock feeding, bedding, insulation and mulch.

The amount of crop residues generated varies by location depending on soil type. Typically, part of the crop residues generated are left on the fields for soil protection from wind and water erosion; however, some farmers practice zero till operations and all of the residues are removed.

Table 1 provides the estimated the amount of wheat straw and oat straw available for industrial applications after deductions of 1.0 t/ha for soil conservation and of the amount needed for livestock feeding and bedding, as developed by Sokhansanj et al[1]. What is clear from their analysis is that the average annual availability of cereal straw in the Canadian Prairies for industrial applications is about 15 million tonnes, but that annual straw availability can swing widely depending on factors such as climate conditions (drought or flooding) as well as location with Saskatchewan having the highest availability followed by Alberta and then Manitoba. These factors will be critical for site selection for an industrial application that will potentially use several hundred thousand tonnes of straw annually.

This study was carried out to establish pulping and TCF bleaching conditions for wheat straw, oat straw and 50/50 wheat straw/oat straw (50/50 mix) to produce paper grade pulps and to evaluate the pulp properties.

## EXPERIMENTAL

All work was carried out at the North Carolina State University Department of Forest Biomaterials laboratory under the direction of HurterConsult.

All tests were conducted in accordance with TAPPI Test Methods.

### Materials

Manitoba wheat straw and oat straw were used for all experiments.

Prior to delivery to NCSU, large bales of wheat straw and oat straw were collected by a third party. The bales were broken and the straw was cut to an acceptable length for the pulping trials. During this process, the samples were contaminated with small white rock particles which were difficult to detect in the raw material before cooking. These particles were screened out of the cooked pulp. It does not appear that these particles interfered with the pulping or bleaching of the test materials because the bleached wheat straw pulp, the bleached oat straw pulp, and the bleached 50/50 wheat/oat straw mixture all exhibited physical and papermaking properties typical for these straws.

### Cooking

The cooking process tested was soda-anthraquinone (soda-AQ). Anthraquinone is a well-known pulping additive that typically produces higher yield and better pulp properties than for pulping using only sodium hydroxide (soda). HurterConsult established a target Kappa number in the range of 10 - 15.

For wheat straw, a total of eight cooks were carried out. Five cooks were done using 3-liter stainless bombs placed on a rotating rack in a heated-air oven, and three were done using a 30-liter direct steamed rotating batch digester.

For oat straw, a total of eight cooks were carried out. Four cooks were done using 3-liter stainless bombs placed on a rotating rack in a heated-air oven. And four were done using a 30-liter direct steamed rotating batch digester.

For the 50/50 wheat straw/oat straw mixture, a total of six cooks were carried out. Three cooks were done using 3-liter stainless bombs placed on a rotating rack in a heated-air oven, and three were done using a 30-liter direct steamed rotating batch digester.

Table 2 provides the range of test conditions used to determine the optimum cooking conditions and the results for the optimum test conditions for the three raw materials.

### Bleaching

Unbleached wheat straw pulp, oat straw pulp and the 50/50 wheat straw/oat straw pulp from their respective optimum cooking trials were initially bleached using a QPp sequence with a target brightness of 85% ISO established by HurterConsult.

The chelation stage (Q) was done in an open container placed into a heated water bath. Pulp was mixed with sulfuric acid to achieve a pH of 5. DTPA was then added, and the mixture was mixed periodically. After reaction, the pulp was washed thoroughly with distilled water.

Pressurized peroxide bleaching (Pp) was done in 3-liter bombs lined with Teflon to reduce peroxide degradation. The bombs were placed on a rotating rack inside of a heated-air oven. Pulp was mixed with chemicals using an industrial kitchen mixer fitted with a kneading spade.

After several trials with each pulp, it became evident that QPp bleaching would not achieve the target brightness for any of the unbleached pulps tested, and the QPp bleached pulps were subjected to an ozone stage making the sequence QPpZ.

Low-consistency bleaching using ozone (Z) was carried out by sparging ozone gas into a mixing vortex of pulp slurry.

After each stage, the pulp was tested for the following: brightness, Kappa number, freeness (CSF), yield, and chemical consumption.

Table 3 provides the optimum bleaching conditions and bleaching chemical charges for the three pulps.

**Papermaking and Testing**

The bleached pulps were refined using a PFI mill and then tested for Canadian Standard Freeness.

Standard handsheets, with a target basis weight of 65 g/m2, were made using a British sheet mould, according to TAPPI standards.

## RESULTS AND DISCUSSION

**Cooking** (Table 4)

At the optimum cooking conditions, the screened yield for the three raw materials was approximately 40% with the 50/50 mix having the highest yield at 41.7% and the wheat straw the lowest at 39.6%.

The pulps all had Kappa numbers below the targeted 10 – 15 range: 8.9 for wheat straw, 8.6 for oat straw and 9.6 for the 50/50 mix.

Alkali consumption was lower than expected ranging from 84.6% for wheat straw to 89.3% for the 50/50 mix.

The screened yield was lower than expected for cereal straws which, based on other commercial information available to the authors, is typically 44 - 46% for soda cooking at these conditions. However, these commercial operations were cooking to a Kappa number in the order of 14 – 15. The lower Kappa numbers of 8.6 – 9.6 tested for the NCSU pulps would account for the lower yields.

**Bleaching** (Table 5)

For wheat straw, QPpZ bleaching achieved brightness to 87.1% ISO brightness. Given that QPp bleaching came close to achieving the target brightness of 85% ISO, optimization of the pressurized peroxide stage may show that ozone is not required or that an atmospheric peroxide stage could replace the ozone stage.

For oat straw, QPpZ bleaching achieved 85.5% ISO brightness, just meeting the target brightness. It appears that oat straw does not react as well to peroxide bleaching compared to wheat straw despite the lower Kappa number of the unbleached oat straw pulp. However, the oat straw pulp reacted very well to ozone bleaching, increasing 8 brightness points in the ozone stage.

For the 50/50 mix, QPpZ bleaching achieved 86.8% ISO brightness.

Bleached pulp viscosity was 14.7 cp for wheat straw, 13.3 cp for oat straw and 17.1 for the 50/50 mix. Although these viscosities are all lower than typical for woodpulps, the final pulp viscosities are still reasonably good for papermaking.

The final kappa number ranged from 0.6 for the 50/50 mix to 1.0 for oat straw, all in the range expected for fully bleached woodpulps.

Pulp freeness after bleaching was 391 ml CSF for wheat straw, 330 ml CSF for oat straw and 352 ml CSF for the 50/50 mix, all of which should allow for further fiber development prior to the paper machine. However, it should be noted that the freeness drop from unbleached to bleached pulp was 162, 53 and 128 ml CSF respectively for wheat straw, oat straw and the 50/50 mix. This shows that wheat straw pulp is more susceptible to mechanical action than oat straw pulp. For the design of a commercial mill, minimizing mechanical action through the bleach plant will be a consideration, especially for wheat straw.

The overall total bleaching yield was 88.0%, 85.8% and 86.9%, respectively for wheat straw, oat straw and the 50/50 mix. Normally, for cereal straws starting with an unbleached Kappa number of about 15, a total bleaching loss in the order of 9% is anticipated. However, the total bleaching yield is showing losses higher than normally anticipated. No explanation was found for the high bleaching losses especially given the low unbleached pulp Kappa numbers.

**Fiber length analysis** (Table 6)

The length-weighted average fiber length for the bleached straw pulps was 1.35mm, 1.39 mm and 1.42 mm, respectively for wheat straw, oat straw and the 50/50 mix, all of which are in the typical range for cereal straws.

All of the bleached straw pulps exhibit a typical high P-fraction, in excess of 30%.

**Bleached Pulp Properties** (Tables 7, 8, 9)

The properties of the soda-AQ cooked and QPpZ bleached pulps are provided in Table 7 for wheat straw, Table 8 for oat straw and Table 9 for the 50/50 mix.

Selected physical properties of the pulps, bleached wheat straw (BWS), bleached oat straw (BOS) and the 50/50 mix are compared with bleached eucalyptus kraft (BEK) pulp in Figures 1 to 7. Values for BEK were obtained from a review by Foelkel (2).

Comparing the BWS, BOS and 50/50 mix pulps, they all had similar tear index, tensile index, burst index and TEA.

Compared to BEK,

- The BWS, BOS and 50/50 mix all had low tear index as was expected for these raw materials, and significantly lower than the BEK tear index.
- Tensile index for the BWS, BOS and 50/50 mix was as good as or higher than that for BEK at the same freeness.
- Burst index for BWS, BOS and the 50/50 mix was significantly higher.
- TEA and bulk for BWS, BOS and the 50/50 mix were lower than for BEK.

## CONCLUSIONS

Canadian wheat straw and oat straw can produce acceptable quality papermaking pulp using the soda-AQ process and TCF bleaching.

Cooking and bleaching yields were lower than expected, and further work to optimize cooking and bleaching conditions could result in improved yield.

Given the vast straw resource, further study of these raw materials is warranted.

## References

1. Sokhansanj, S., Mani, S., Stumborg, M., Samson, R. and Fenton, J. “Production and distribution of cereal straw on the Canadian Prairies”, Canadian Biosystems Engineering, 2006, 48: 3.39 - 3.46.

2. Celso Foelkel, “The Eucalyptus Fibers and the Kraft Pulp Quality Requirements for Paper Manufacturing”, Eucalyptus Online Book & Newsletter, February/March 2007.

**Table 1 Straw available for industrial applications in Canadian Prairie provinces for years 1994 - 2003**

| Cereal Grains | | Alberta (Mt) | Saskatchewan (Mt) | Manitoba (Mt) | Total (Mt) |
|---|---|---|---|---|---|
| Wheat | avg | 5.089 | 7.176 | 1.585 | 13.850 |
| | max | 6.567 | 11.704 | 3.748 | 22.020 |
| | min | 2.598 | 2.680 | 0 | 5.278 |
| Barley | avg | 2.605 | 1.784 | 0.462 | 4.851 |
| | max | 3.954 | 2.838 | 1.227 | 8.019 |
| | min | 0.935 | 0.580 | 0 | 1.515 |
| Oat | avg | 0.534 | 0.911 | 0.493 | 1.938 |
| | max | 0.877 | 1.435 | 0.976 | 3.287 |
| | min | 0.211 | 0.453 | 0.009 | 0.672 |
| Flax | avg | 0.017 | 0.195 | 0.026 | 0.238 |
| | max | 0.032 | 0.391 | 0.322 | 0.745 |
| | min | 0.009 | 0.054 | 0 | 0.063 |
| Total after soil conservation deductions | avg | 8.776 | 9.751 | 2.399 | 20.926 |
| | max | 12.071 | 15.744 | 5.712 | 33.527 |
| | min | 4.271 | 3.946 | 0 | 11.392 |
| Total after soil conservation and livestock deductions | avg | 5.574 | 7.938 | 1.509 | 15.021 |
| | max | 8.869 | 13.931 | 4.822 | 27.622 |
| | min | 1.069 | 2.133 | -0.890 | 2.313 |

| Table 2 Cooking apparatus & conditions | | | | |
|---|---|---|---|---|
| | Range | Optimum | | |
| | | Wheat straw | Oat straw | 50/50 mix |
| Cooking apparatus | a) two 3-liter bombs on rotating rack in heated-air oven<br>b) direct steamed 30-liter batch digester | direct steamed 30-liter batch digester | direct steamed 30-liter batch digester | direct steamed 30-liter batch digester |
| Sample size | 170 - 600 od grams | 600 od grams | 600 od grams | 600 od grams |
| NaOH on OD fiber | 13 - 14% | 14% | 14% | 14% |
| AQ on OD fiber | 0.05 - 0.07% | 0.07% | 0.07% | 0.07% |
| Liquor-to-fiber ratio | 5:1 | 5:1 start | 5:1 start | 5:1 start |
| Maximum temp. | 150 - 160 $^0$C | 160 $^0$C | 160 $^0$C | 160 $^0$C |
| Time to max temp. | 60 minutes | 60 minutes | 60 minutes | 60 minutes |
| Time at max temp. | 60 minutes | 60 minutes | 60 minutes | 60 minutes |
| Post cooking treatment | mixed, washed and screened | mixed, washed and screened | mixed, washed and screened | mixed, washed and screened |

| Table 3 Bleaching conditions | | | | | | |
|---|---|---|---|---|---|---|
| | | | Range | Optimum | | |
| | | | | Wheat straw | Oat straw | 50/50 mix |
| Sequence | | | QPpZ | QPpZ | QPpZ | QPpZ |
| Q stage | consistency | % | 4.0 | 4.0 | 4.0 | 4.0 |
| | temperature | $^0$C | 55 | 55 | 55 | 55 |
| | time | minutes | 35 | 35 | 35 | 35 |
| | pH | | 5 | 5 | 5 | 5 |
| | DTPA | % on od fiber | 0.5 | 0.5 | 0.5 | 0.5 |
| Pp stage | consistency | % | 12.0 | 12.0 | 12.0 | 12.0 |
| | temperature | $^0$C | 105 | 105 | 105 | 105 |
| | time | minutes | 90 | 90 | 90 | 90 |
| | $H_2O_2$ | % on od fiber | 3.0 – 4.0 | 4.0 | 4.0 | 4.0 |
| | NaOH | % on od fiber | 3.0 – 4.0 | 4.0 | 4.0 | 4.0 |
| | DTMPA | % on od fiber | 0.2 | 0.2 | 0.2 | 0.2 |
| | $MgSO_4$ | % on od fiber | 0.5 | 0.5 | 0.5 | 0.5 |
| | $Na_2SiO_3$ | % on od fiber | 0.5 | 0.5 | 0.5 | 0.5 |
| Z stage | consistency | % | 3.0 | 3.0 | 3.0 | 3.0 |
| | temperature | $^0$C | 20 (room) | 20 | 20 | 20 |
| | pH | | 1.5 – 1.6 | 1.5 | 1.5 | 1.5 |

| Table 4 Cooking results | | | |
|---|---|---|---|
| | **Wheat straw** | **Oat straw** | **50/50 mix** |
| Kappa number | 8.9 | 8.6 | 9.6 |
| ISO brightness | 39.6% | 37.2% | 34.5% |
| Total yield | 40.1% | 40.5% | 42.7% |
| Screened yield | 39.6% | 40.3% | 41.7% |
| Screened rejects | 1.1% | 0.5% | 2.4% |
| Screened pulp freeness, ml CSF | 553 | 383 | 480 |
| Alkali consumption | 84.6% | 86.9% | 89.3% |
| Black liquor terminal pH | 11.8 | 11.4 | 11.4 |

| Table 5 Bleaching results | | | | | |
|---|---|---|---|---|---|
| | | | **Wheat straw** | **Oat straw** | **50/50 mix** |
| Sequence | | | QPpZ | QPpZ | QPpZ |
| Pp stage | Brightness | % ISO | 83.4 | 77.5 | 80.8 |
| | Kappa number | | 2.7 | 3.0 | 2.5 |
| | Freeness | Ml CSF | 493 | | |
| | Pulp yield | % | 94.5 | 91.7 | 93.5 |
| | Initial / final pH | | 11.6 / 11.5 | 11.7 / 11.2 | 11.5 / 11.2 |
| | $H_2O_2$ consumption | % on od fiber | 91.6 | 94.4 | 83.7 |
| Z stage | Brightness | | 87.1 | 85.5 | 86.8 |
| | Kappa number | | 0.7 | 1.0 | 0.6 |
| | Freeness | | 391 | 330 | 352 |
| | Pulp yield | % | 93.1 | 93.6 | 93.4 |
| | Initial / final pH | | 1.5 / 1.6 | 1.7 / 1.7 | 1.5 / 1.6 |
| | $O_3$ consumption | % on od fiber | 0.9 | 0.8 | 0.6 |
| Bleached Pulp | | | | | |
| | Viscosity | cp | 14.7 | 13.3 | 17.1 |
| | Total bleaching yield | % | 88.0 | 85.8 | 86.9 |

| Table 6  Kajaani fiber length distribution | | | | |
|---|---|---|---|---|
| | | **Wheat straw** | **Oat straw** | **50/50 mix** |
| Arithmetic average | mm | 0.52 | 0.55 | 0.56 |
| Length-weighted average | mm | 1.35 | 1.39 | 1.42 |
| Weight-weighted average | mm | 2.97 | 2.94 | 2.97 |
| P-fraction | % | 34.11 | 30.60 | 30.69 |

| Table 7  Bleached pulp properties – wheat straw (87.1% ISO) | | | | | |
|---|---|---|---|---|---|
| **Test** | **Units** | | | | |
| PFI revolutions | rev | 0 | 30 | 70 | 200 |
| Freeness | CSF, ml | 350 | 290 | 274 | 228 |
| Basis weight | $g/m^2$ | 64.25 | 65.63 | 67.20 | 67.50 |
| Density | $g/cm^3$ | 0.793 | 0.802 | 0.817 | 0.828 |
| Bulk | $cm^3/g$ | 1.26 | 1.25 | 1.22 | 1.21 |
| Tear Index | $mN \cdot m^2/g$ | 4.97 | 5.41 | 5.25 | 5.17 |
| Tensile Index | Nm/g | 65.21 | 68.84 | 69.14 | 70.02 |
| Burst Index | $kPa \cdot m^2/g$ | 4.78 | 5.27 | 5.60 | 5.57 |
| Stretch | % | 2.91 | 2.46 | 2.62 | 2.71 |
| TEA | J/m2 | 72.94 | 91.24 | 87.88 | 84.22 |
| Gurley porosity | sec/100 ml | 242.2 | 346.0 | 361.6 | 593.5 |
| TAPPI opacity | % | 75.9 | 73.8 | 75.7 | 74.7 |
| Printing opacity | % | 69.1 | 67.4 | 68.3 | 67.5 |

| Table 8 Bleached pulp properties – oat straw (85.5% ISO) | | | | | |
|---|---|---|---|---|---|
| **Test** | **Units** | | | | |
| PFI revolutions | rev | 0 | 200 | 700 | |
| Freeness | CSF, ml | 289 | 195 | 146 | |
| Basis weight | $g/m^2$ | 65.16 | 65.82 | 65.20 | |
| Density | $g/cm^3$ | 0.737 | 0.807 | 0.841 | |
| Bulk | $cm^3/g$ | 1.36 | 1.24 | 1.19 | |
| Tear Index | $mN \cdot m^2/g$ | 5.27 | 4.68 | 4.62 | |
| Tensile Index | Nm/g | 70.60 | 71.20 | 71.78 | |
| Burst Index | $kPa \cdot m^2/g$ | 5.64 | 6.51 | 6.63 | |
| Stretch | % | 2.64 | 2.21 | 2.43 | |
| TEA | J/m2 | 82.64 | 77.27 | 65.86 | |
| Gurley porosity | sec/100 ml | 201.5 | 1262.1 | 1077.1 | |
| Drain factor | sec | 11.50 | 18.25 | 26.32 | |
| TAPPI opacity | % | 79.0 | 72.6 | 73.9 | |
| Printing opacity | % | 69.9 | 63.6 | 63.5 | |

| Table 9 Bleached pulp properties – 50/50 wheat/oat straws (86.8% ISO) | | | | | |
|---|---|---|---|---|---|
| **Test** | **Units** | | | | |
| PFI revolutions | rev | 0 | 30 | 90 | 500 |
| Freeness | CSF, ml | 307 | 253 | 231 | 195 |
| Basis weight | $g/m^2$ | 63.70 | 63.0 | 66.00 | 66.73 |
| Density | $g/cm^3$ | 0.740 | 0.799 | 0.815 | 0.834 |
| Bulk | $cm^3/g$ | 1.35 | 1.25 | 1.23 | 1.20 |
| Tear Index | $mN \cdot m^2/g$ | 5.37 | 4.71 | 4.35 | 4.30 |
| Tensile Index | Nm/g | 71.39 | 72.18 | 74.73 | 79.24 |
| Burst Index | $kPa \cdot m^2/g$ | 5.92 | 6.21 | 6.26 | 6.70 |
| Stretch | % | 3.31 | 2.65 | 2.44 | 2.42 |
| TEA | J/m2 | 111.50 | 81.37 | 81.28 | 79.30 |
| Gurley porosity | sec/100 ml | 164.7 | 532.9 | 699.1 | 1384.9 |
| Drain factor | sec | 10.73 | 13.35 | 13.04 | 17.69 |
| TAPPI opacity | % | 77.3 | 73.5 | 72.3 | 70.1 |
| Printing opacity | % | 69.3 | 65.3 | 65.1 | 70.7 |

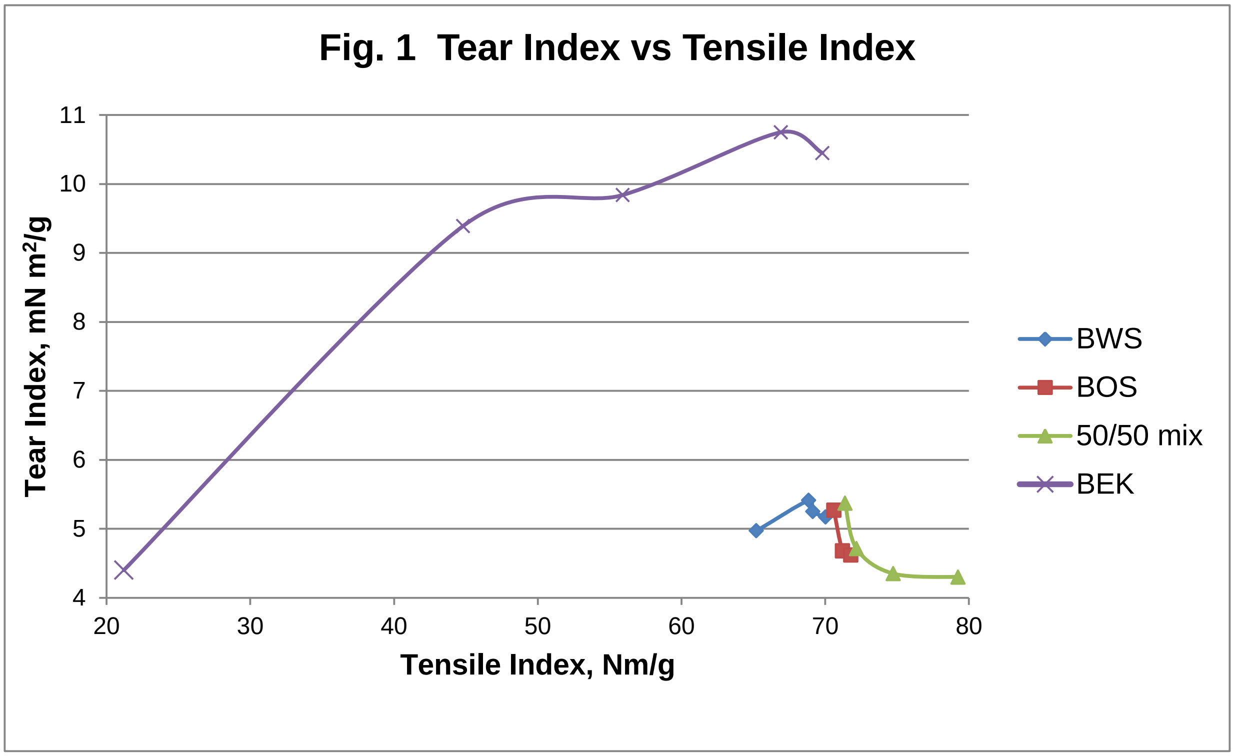


Fig. 1 Tear Index vs Tensile Index
Tear Index, mN m2/g
Tensile Index, Nm/g
11
10
9
8
7
6
5
4
20
30
40
50
60
70
80
BWS
BOS
50/50 mix
BEK

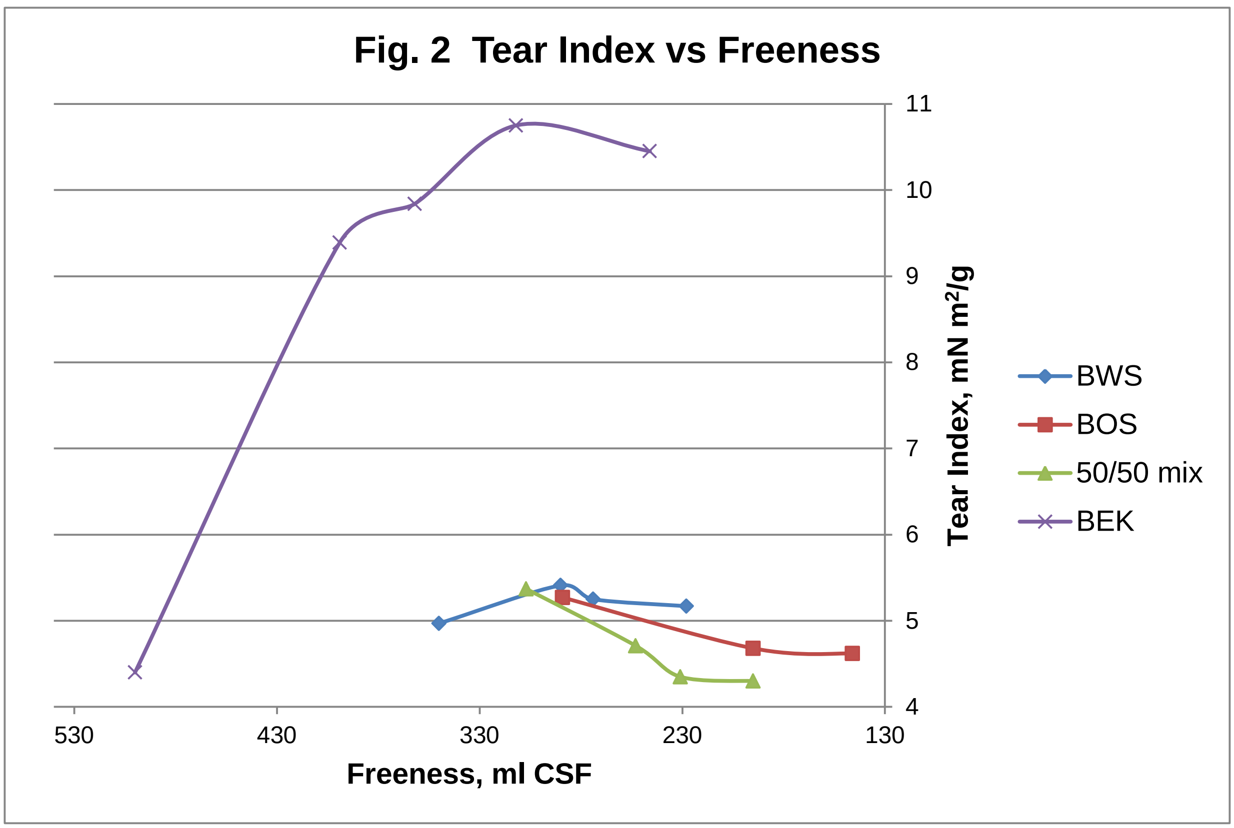


Fig. 2 Tear Index vs Freeness
Tear Index, mN m2/g
Freeness, ml CSF
11
10
9
8
7
6
5
4
530
430
330
230
130
BWS
BOS
50/50 mix
BEK

Fig. 3  Tensile Index vs Freeness

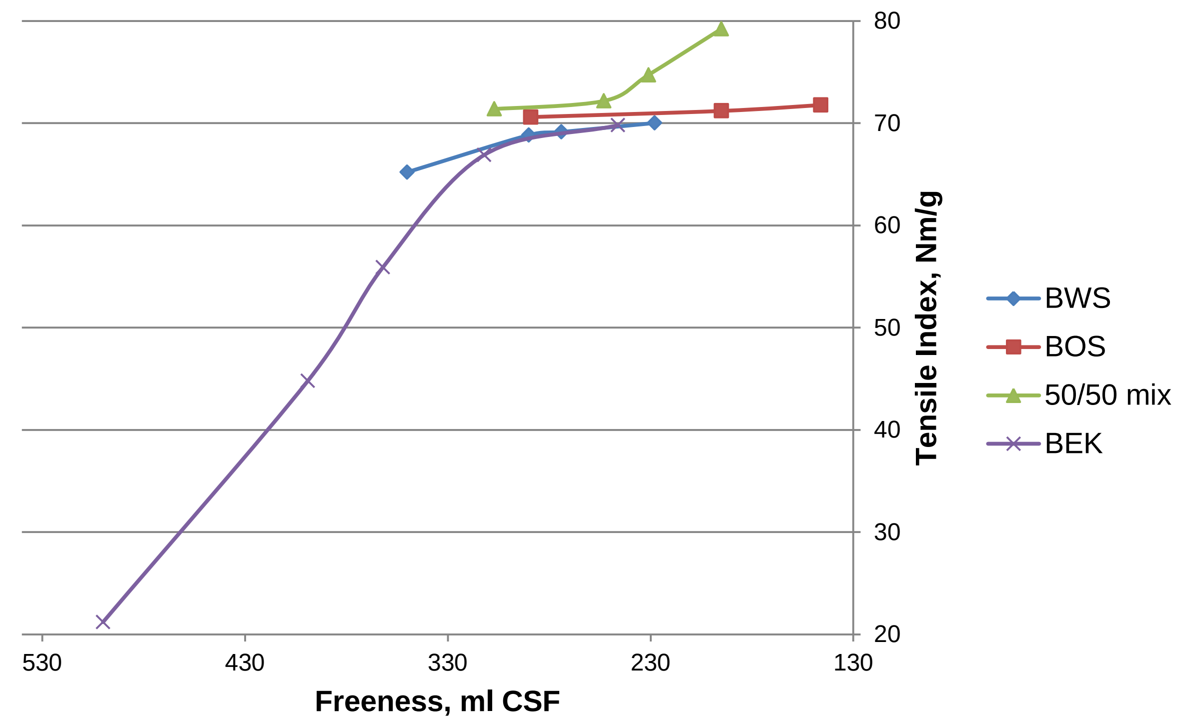



Fig. 4  Burst Index vs Freeness

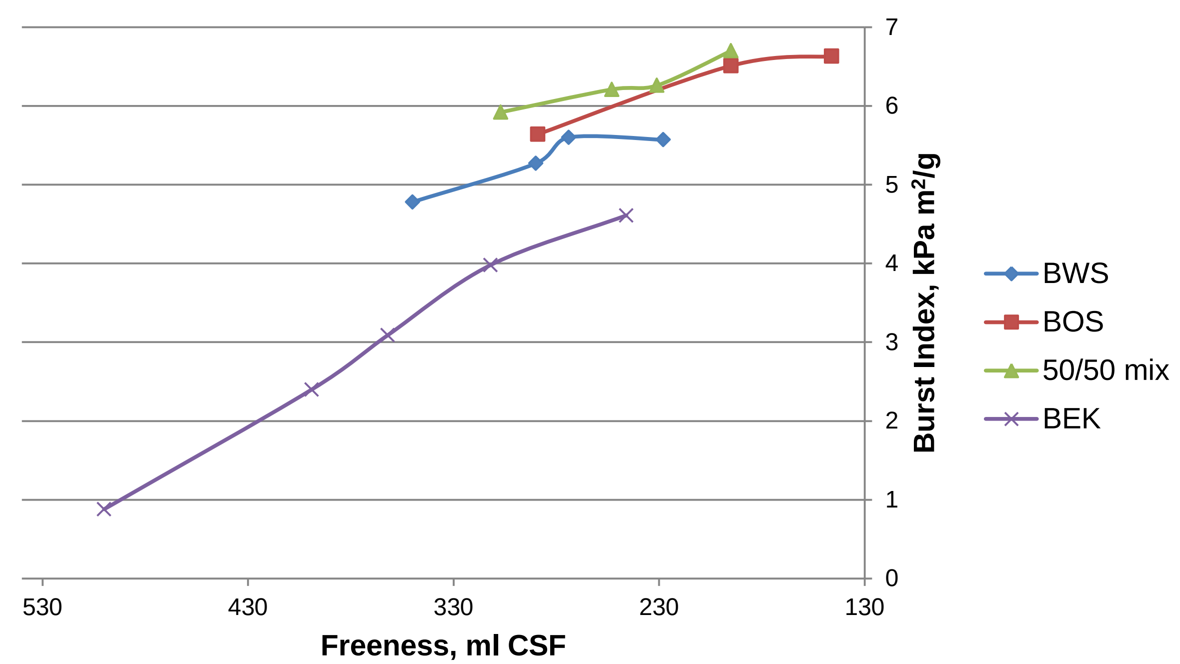


Fig. 5  TEA vs Freeness

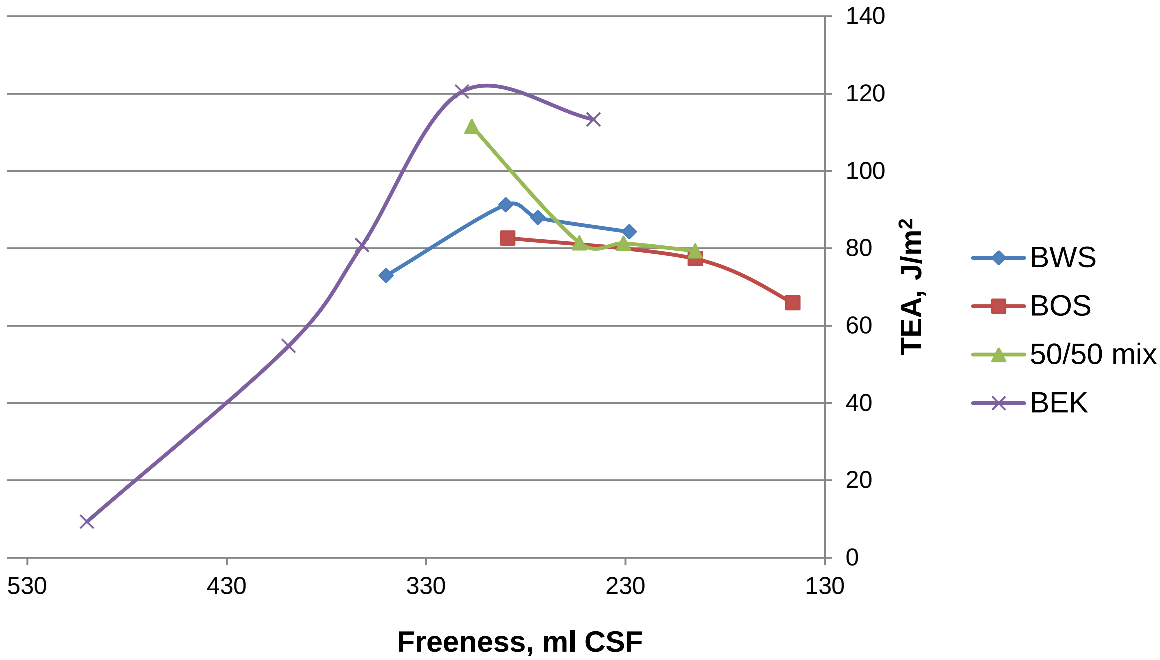
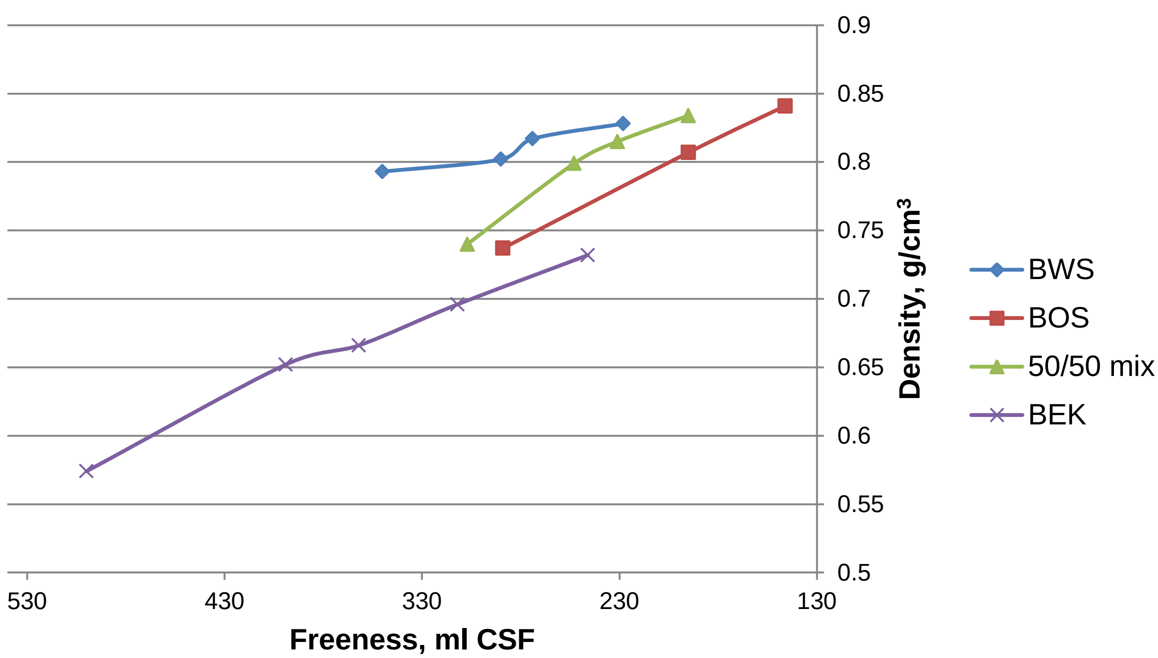



Fig. 6  Density vs Freeness



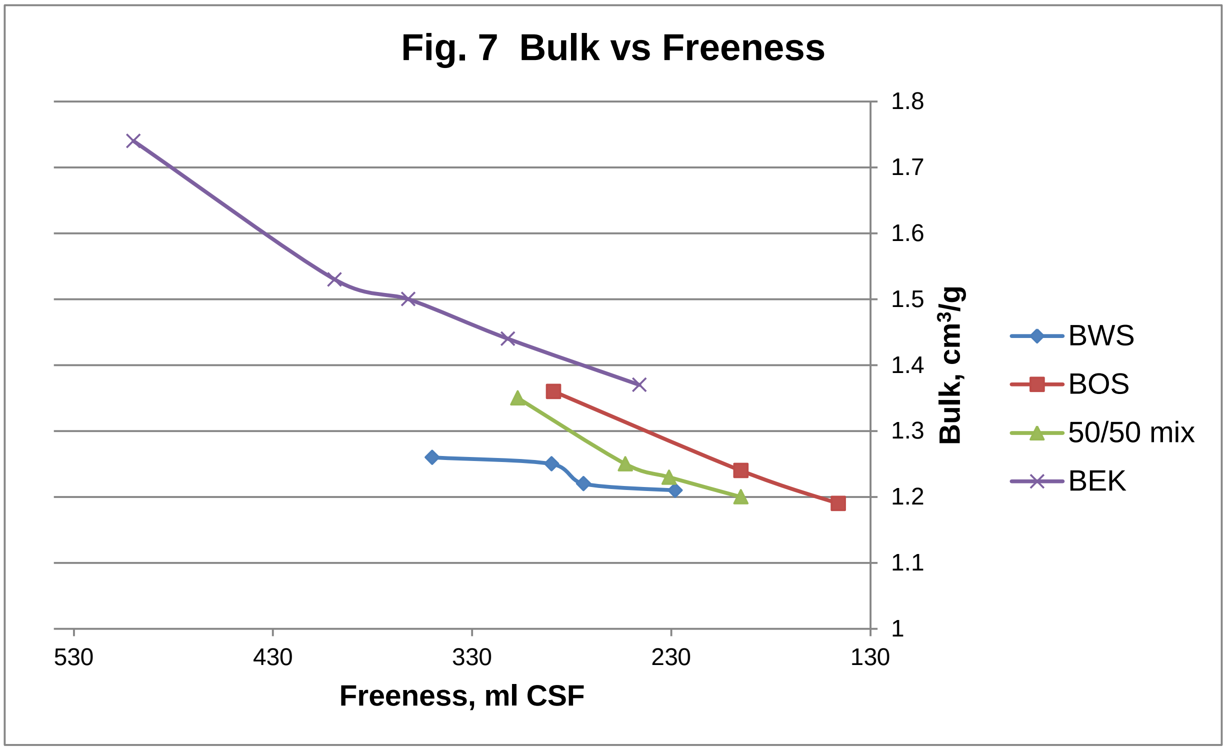


Fig. 7  Bulk vs Freeness
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
530
430
330
230
130
Freeness, ml CSF
Bulk, cm³/g
BWS
BOS
50/50 mix
BEK

# Pulping and TCF Bleaching of Canadian Wheat Straw and Oat Straw

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# Agenda

- Introduction
- Experimental
- Results
- Conclusions

# Introduction

- ~ 36.4 million hectares (Mha) of crop land in Canada
- ~ 34 Mha in the Canadian Prairie provinces
- Cereal crops dominate seeded area, followed by oilseed and pulse crops.
- Most crop residues left on field.
- Some residues used for livestock feeding & bedding, insulation & mulch.
- This paper is focussed on pulping & TCF bleaching of wheat straw, oat straw and a 50/50 mix of the two straws
- This work was part of a larger study.

## Straw available for industrial applications in Canadian Prairie provinces for years 1994 - 2003

| Cereal Grains | | Alberta (Mt) | Saskatchewan (Mt) | Manitoba (Mt) | Total (Mt) |
|---|---|---|---|---|---|
| Wheat | avg | 5.089 | 7.176 | 1.585 | 13.850 |
| | max | 6.567 | 11.704 | 3.748 | 22.020 |
| | min | 2.598 | 2.680 | 0 | 5.278 |
| Oat | avg | 0.534 | 0.911 | 0.493 | 1.938 |
| | max | 0.877 | 1.435 | 0.976 | 3.287 |
| | min | 0.211 | 0.453 | 0.009 | 0.672 |
| Total after soil conservation deductions | avg | 8.776 | 9.751 | 2.399 | 20.926 |
| | max | 12.071 | 15.744 | 5.712 | 33.527 |
| | min | 4.271 | 3.946 | 0 | 11.392 |
| Total after soil conservation and livestock deductions | avg | 5.574 | 7.938 | 1.509 | 15.021 |
| | max | 8.869 | 13.931 | 4.822 | 27.622 |
| | min | 1.069 | 2.133 | -0.890 | 2.313 |

# Experimental

- **Fiber raw material**
  - Manitoba wheat straw and oat straw
  - Delivered pre-cut to 25 – 50 mm length

# Experimental

- **Cooking**
  - Process: soda-AQ
  - Target Kappa number: 10 - 15
  - NaOH charge: 13 - 14% on o.d. fiber
  - AQ charge: 0.05 – 0.07% on o.d. fiber
  - Temperature: 150 – 160 $^{0}$C
  - 3-liter rotating bombs, heated-air oven
  - 30-liter direct steamed rotating batch digester

# Experimental

| Optimum cooking conditions | | | |
|---|---|---|---|
| | **Wheat straw** | **Oat straw** | **50/50 mix** |
| Cooking apparatus | direct steamed 30-liter batch digester | direct steamed 30-liter batch digester | direct steamed 30-liter batch digester |
| Sample size | 600 od grams | 600 od grams | 600 od grams |
| NaOH on OD fiber | 14% | 14% | 14% |
| AQ on OD fiber | 0.07% | 0.07% | 0.07% |
| Liquor-to-fiber ratio | 5:1 start | 5:1 start | 5:1 start |
| Maximum temp. | 160 $^0$C | 160 $^0$C | 160 $^0$C |
| Time to max temp. | 60 min | 60 min | 60 min |
| Time at max temp. | 60 min | 60 min | 60 min |
| Post cooking treatment | mixed, washed and screened | mixed, washed and screened | mixed, washed and screened |

# Experimental

- **Bleaching**
  - Target brightness: >85% ISO
  - Initial sequence: QPp
    - Q stage: open container in hot water bath
    - Pp stage: 3-liter Teflon lined bombs
  - Added: Z stage
    - Z stage: sparged ozone gas into mixing vortex of pulp slurry

# Experimental

| Bleaching conditions – Q stage | | |
|---|---|---|
| Consistency | % | 4.0 |
| Temperature | $^{0}C$ | 55 |
| Time | minutes | 35 |
| pH | | 5 |
| DTPA | % on od fiber | 0.5 |

# Experimental

| Bleaching conditions – Pp stage | | | |
|---|---|---|---|
| | | **Range** | **Optimum** |
| Consistency | % | 12.0 | 12.0 |
| Temperature | $^{0}C$ | 105 | 105 |
| Time | minutes | 90 | 90 |
| $H_2O_2$ | % on od fiber | 3.0 – 4.0 | 4.0 |
| NaOH | % on od fiber | 3.0 – 4.0 | 4.0 |
| DTMPA | % on od fiber | 0.2 | 0.2 |
| $MgSO_4$ | % on od fiber | 0.5 | 0.5 |
| $Na_2SiO_3$ | % on od fiber | 0.5 | 0.5 |

# Experimental

| Bleaching conditions – Z stage | | | |
|---|---|---|---|
| | | **Range** | **Optimum** |
| Consistency | % | 3.0 | 3.0 |
| Temperature | $^0$C | 20 (room) | 20 |
| pH | | 1.5 – 1.6 | 1.5 |

# Results

- Cooking results
- Bleaching results
- Brightness reversion
- Fiber length analysis
- Strength
- All tests conducted according to TAPPI Test Methods

# Results

| Cooking results | | | |
|---|---|---|---|
| | **Wheat straw** | **Oat straw** | **50/50 mix** |
| Kappa number | 8.9 | 8.6 | 9.6 |
| ISO brightness | 39.6% | 37.2% | 34.5% |
| Total yield | 40.1% | 40.5% | 42.7% |
| Screened yield | 39.6% | 40.3% | 41.7% |
| Screened rejects | 1.1% | 0.5% | 2.4% |
| Screened pulp freeness, ml CSF | 553 | 383 | 480 |
| Alkali consumption | 84.6% | 86.9% | 89.3% |
| Black liquor terminal pH | 11.8 | 11.4 | 11.4 |

# Results

| Bleaching results – P stage | | | | |
|---|---|---|---|---|
| | | **Wheat straw** | **Oat straw** | **50/50 mix** |
| Brightness | % ISO | 83.4 | 77.5 | 80.8 |
| Kappa number | | 2.7 | 3.0 | 2.5 |
| Freeness | ml CSF | 493 | | |
| Pulp yield | % | 94.5 | 91.7 | 93.5 |
| Initial / final pH | | 11.6 / 11.5 | 11.7 / 11.2 | 11.5 / 11.2 |
| $H_2O_2$ consumption | % on od fiber | 91.6 | 94.4 | 83.7 |

# Results

| Bleaching results – Z stage | | | | |
|---|---|---|---|---|
| | | **Wheat straw** | **Oat straw** | **50/50 mix** |
| Brightness | | 87.1 | 85.5 | 86.8 |
| Kappa number | | 0.7 | 1.0 | 0.6 |
| Freeness | | 391 | 330 | 352 |
| Pulp yield | % | 93.1 | 93.6 | 93.4 |
| Initial / final pH | | 1.5 / 1.6 | 1.7 / 1.7 | 1.5 / 1.6 |
| $O_3$ consumption | % on od fiber | 0.9 | 0.8 | 0.6 |
| **Bleached Pulp** | | | | |
| Viscosity | cp | 14.7 | 13.3 | 17.1 |
| Total bleaching yield | % | 88.0 | 85.8 | 86.9 |

# Results

| Kajaani fiber length distribution | | | | |
|---|---|---|---|---|
| | | **Wheat straw** | **Oat straw** | **50/50 mix** |
| Arithmetic average | mm | 0.52 | 0.55 | 0.56 |
| Length-weighted average | mm | 1.35 | 1.39 | 1.42 |
| Weight-weighted average | mm | 2.97 | 2.94 | 2.97 |
| P-fraction | % | 34.11 | 30.60 | 30.69 |

# Results

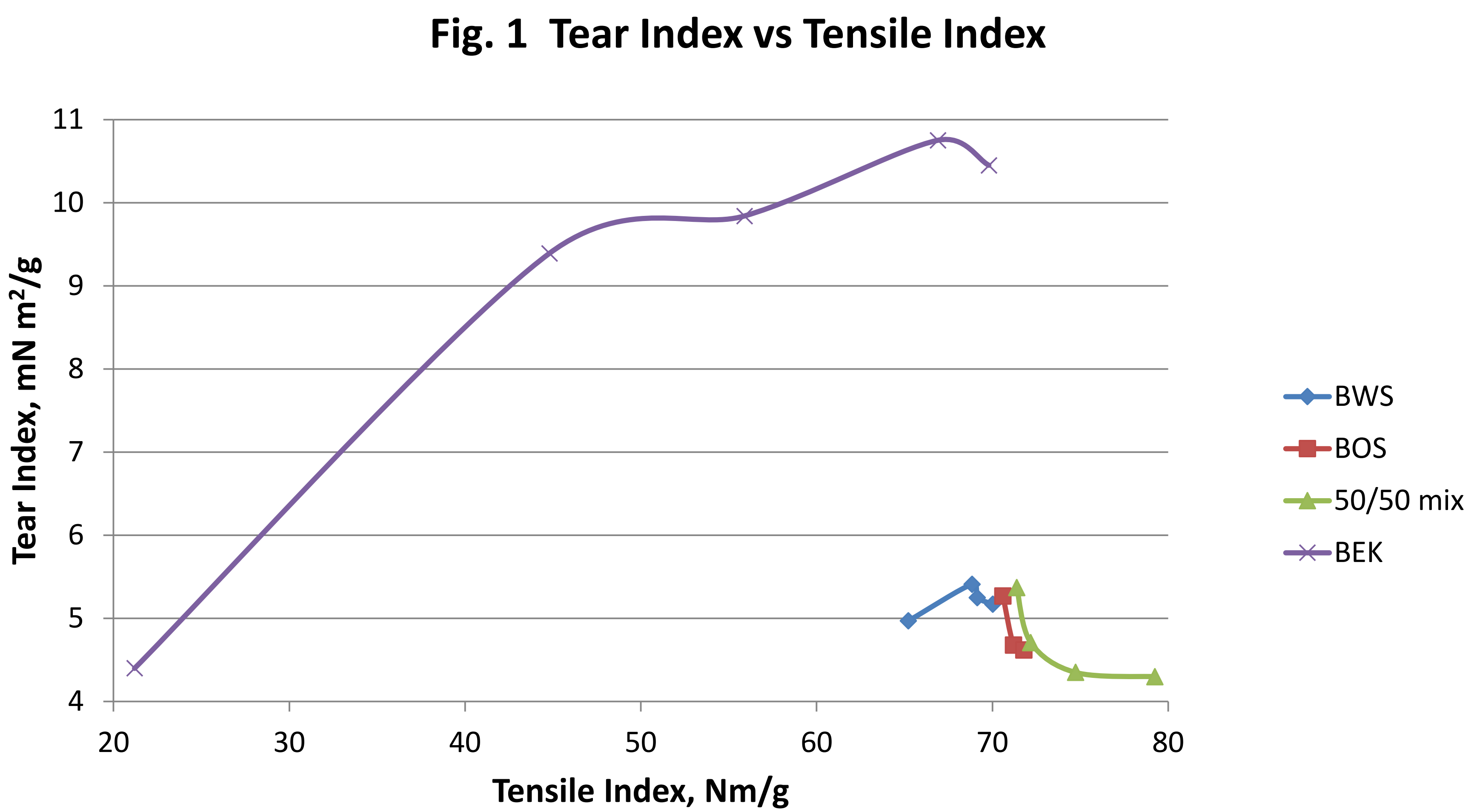

Fig. 1 Tear Index vs Tensile Index
Tear Index, mN m²/g
11
10
9
8
7
6
5
4
20
30
40
50
60
70
80
Tensile Index, Nm/g
BWS
BOS
50/50 mix
BEK

# Results

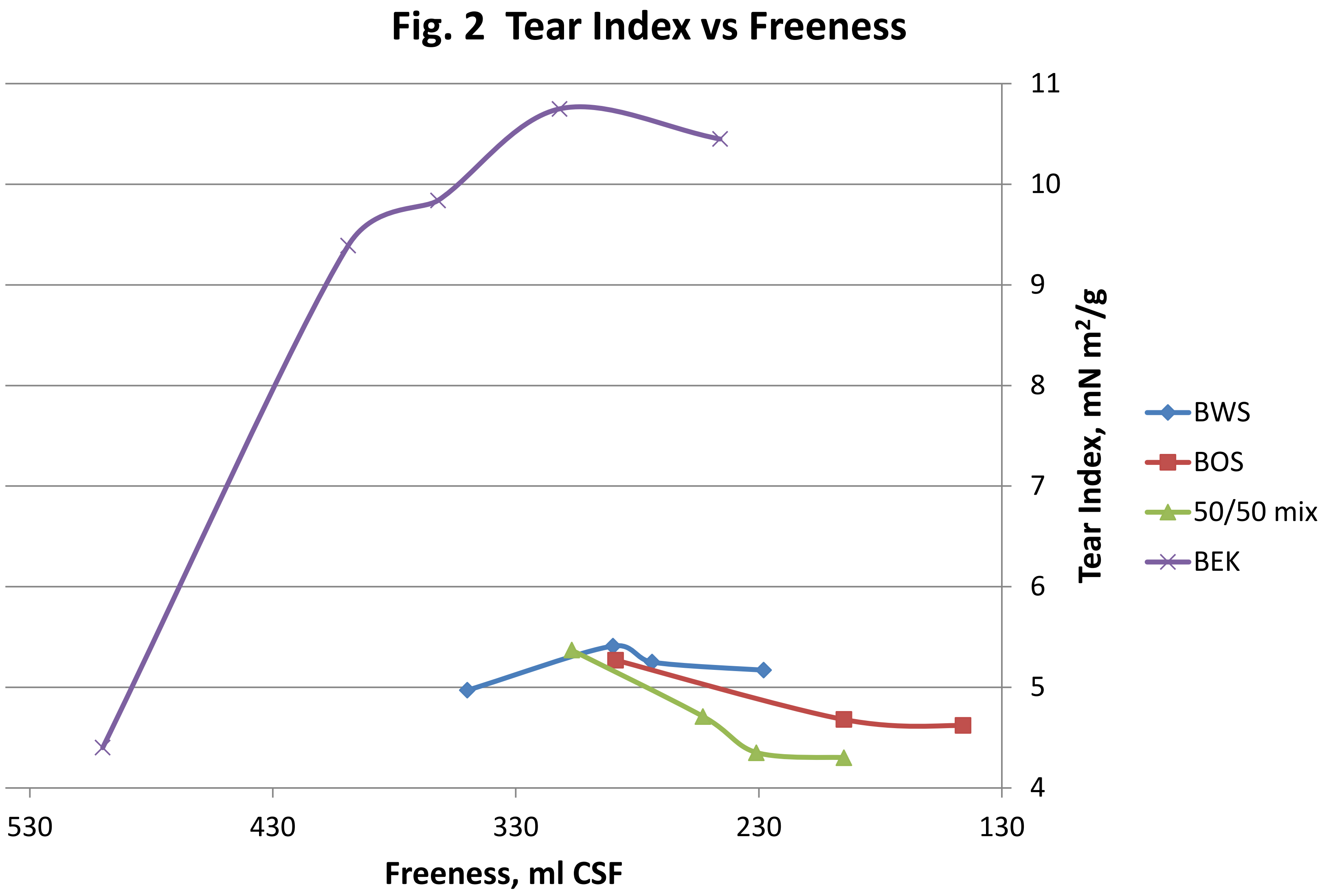

Fig. 2 Tear Index vs Freeness
11
10
9
8
7
6
5
4
530
430
330
230
130
Freeness, ml CSF
Tear Index, mN m2/g
BWS
BOS
50/50 mix
BEK

# Results

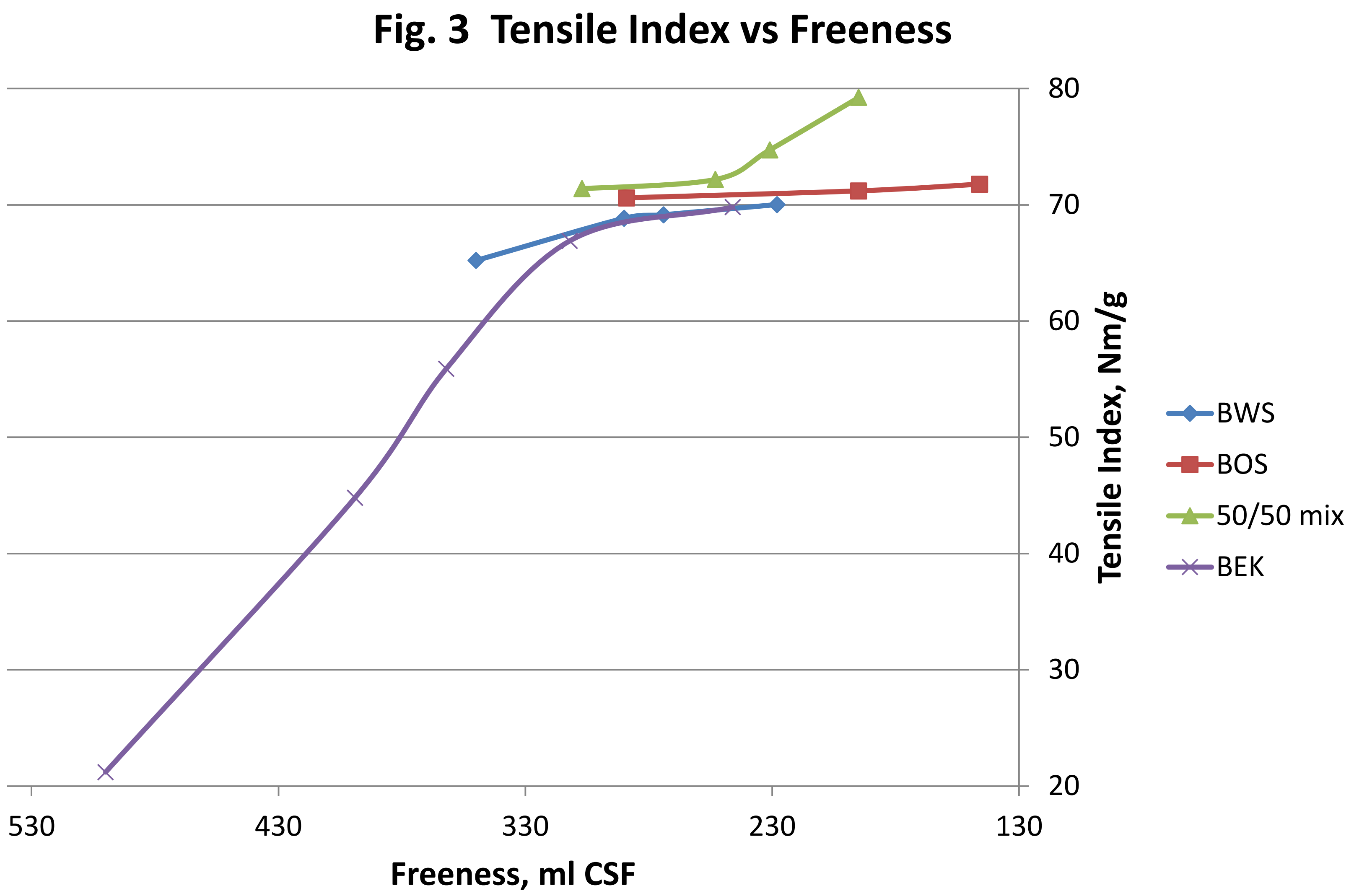

Fig. 3 Tensile Index vs Freeness
80
70
60
50
40
30
20
Tensile Index, Nm/g
530
430
330
230
130
Freeness, ml CSF
BWS
BOS
50/50 mix
BEK

# Results

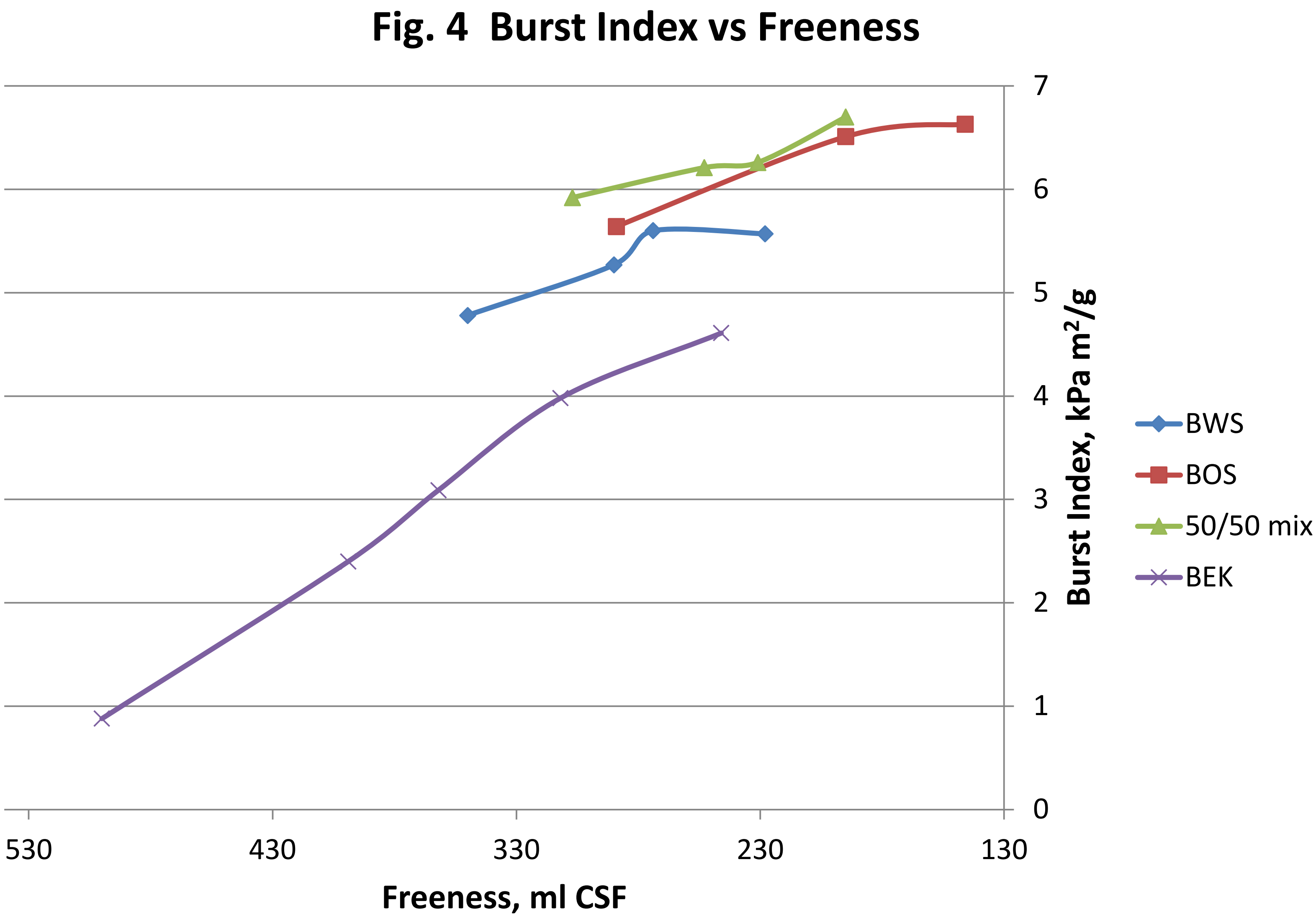

Fig. 4 Burst Index vs Freeness
7
6
5
4
3
2
1
0
530
430
330
230
130
Freeness, ml CSF
Burst Index, kPa m²/g
BWS
BOS
50/50 mix
BEK

# Results

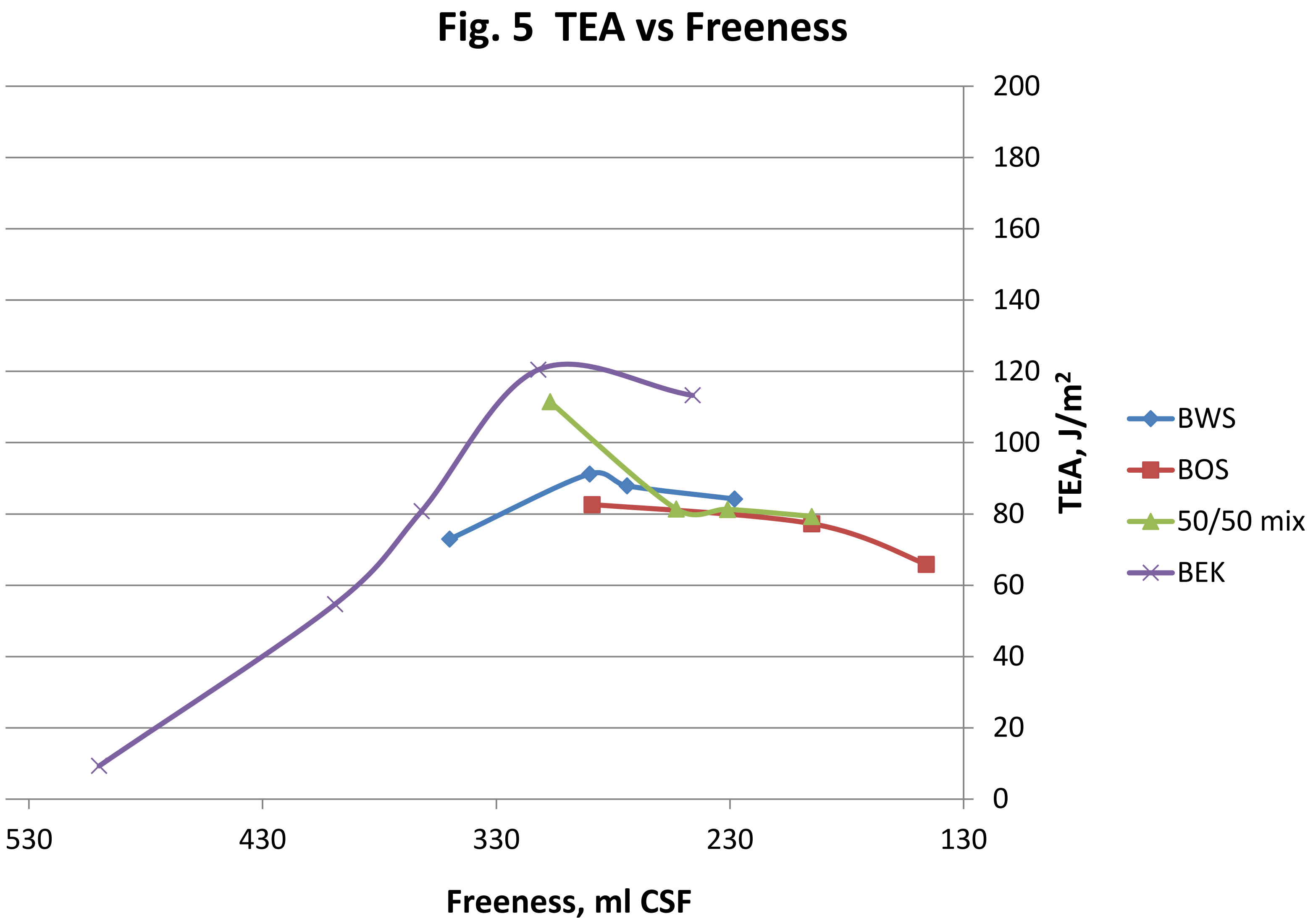
Fig. 5 TEA vs Freeness
200
180
160
140
120
100
80
60
40
20
0
TEA, J/m2
530
430
330
230
130
Freeness, ml CSF
BWS
BOS
50/50 mix
BEK

# Results

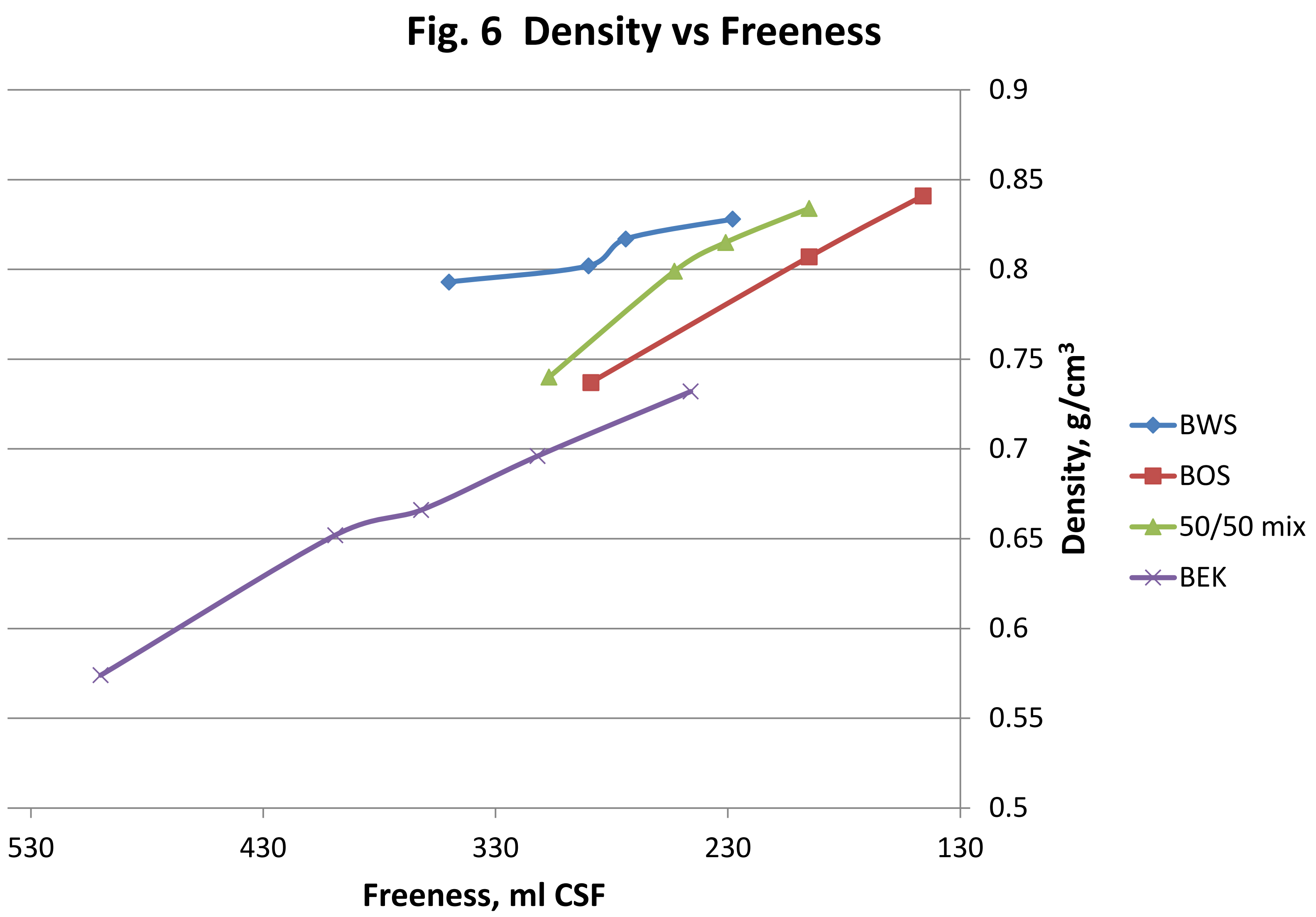

Fig. 6 Density vs Freeness
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
Density, g/cm3
530
430
330
230
130
Freeness, ml CSF
BWS
BOS
50/50 mix
BEK

# Results

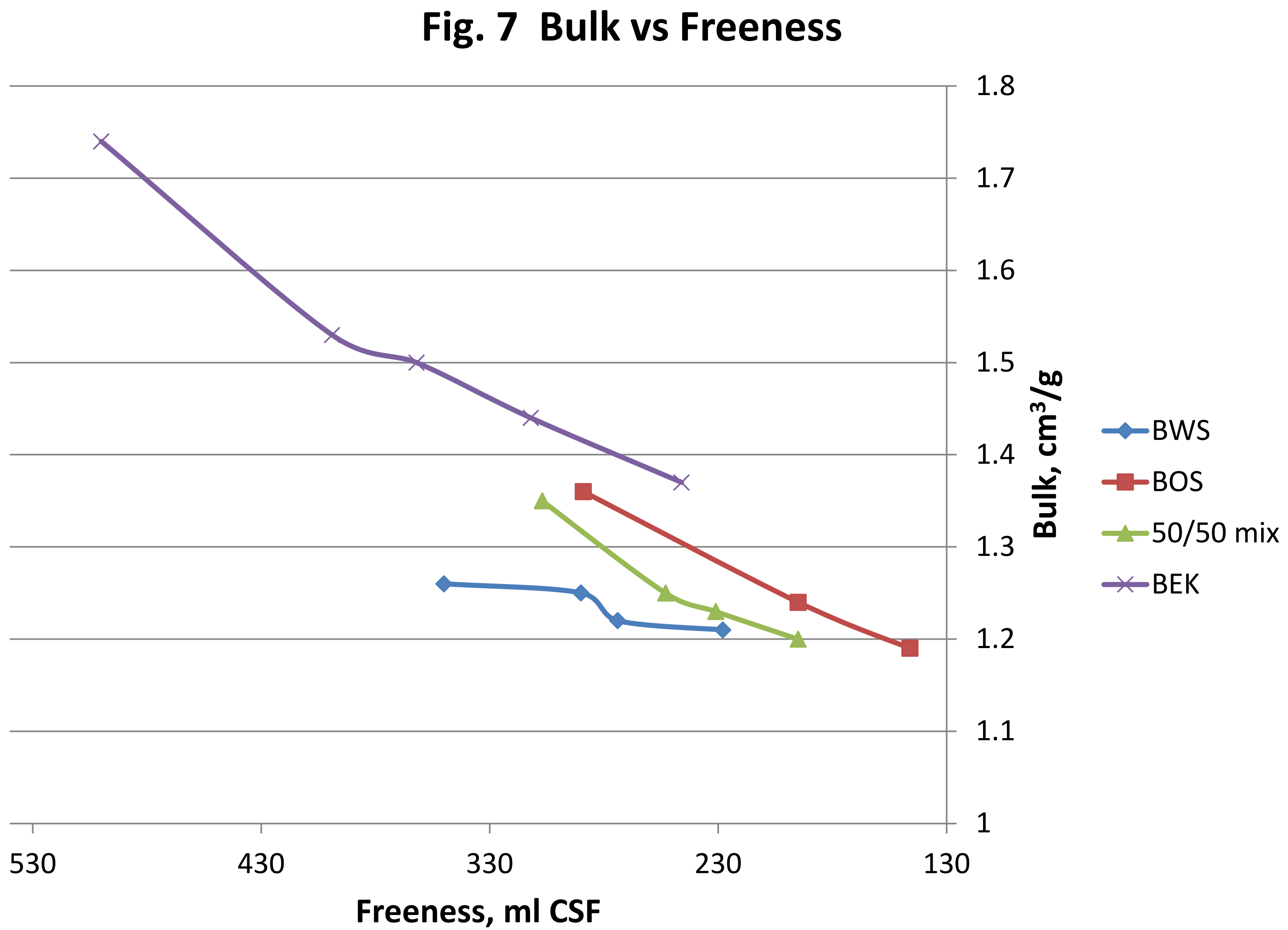
Fig. 7 Bulk vs Freeness
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
530
430
330
230
130
Freeness, ml CSF
Bulk, cm3/g
BWS
BOS
50/50 mix
BEK

# Conclusions

- Canadian wheat straw and oat straw can produce acceptable quality papermaking pulp using the soda-AQ process and TCF bleaching.
- Cooking and bleaching yields were lower than expected, further work to optimize conditions could improve yield.
- Further study of alternative bleaching sequences such as QPpP and ZPp may be warranted.
- Given the vast straw resource, further study of these raw materials is warranted.
- Watch for our next paper on industrial hemp which was part of the larger study involving this work.

# Questions?

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