The Development of Physical Properties and Correlation of Feed and Product Sizes and Energy Consumption During Vibratory Ring & Puck Fine Milling of Douglas-fir Wood Particles

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Introduction

◆ Mechanical fine grinding has been proved to be able to break down biomass recalcitrance very effectively to namely, reduce particle size leading to disruption of robust hierarchical structure of cell wall, weaken interactions among macromolecules, increase specific surface area, and decrease cellulose crystallinity, which generally make the polysaccharide more accessible and susceptible to efficient enzyme attack[1-2].

◆ Mechanical grinding pretreatment gets renascent attention in pretreatment arena, because it features no use of cheimicals, less inhibitory compounds production, and flexible simple pretreatment process.

◆ However, the intensive energy requirement for mechanical fine grinding of biomass limits its industrial scale application in biorefinary. Grinding energy consumption is believed to be affected by various factors including milling types, degree of material evolution, material charge of grinding circuit, moisture content and feed size of starting material[3-4].

◆ Understanding the physical properties evolution of particles after mechanical grinding is the first step to optimize the technical feasibility of milling pretreatment. Moreover, the relationship correlating grinding energy consumption and characterization of feed and product particle size will benefit to evaluation of grindability of biomass for economical feasible up-scale application.

Objectives

- To investigate different factors related to starting material on development of physical properties of fine ground wood particles.
- To correlate grinding energy consumption and feed and product particle characteristic size.

Experimental methods

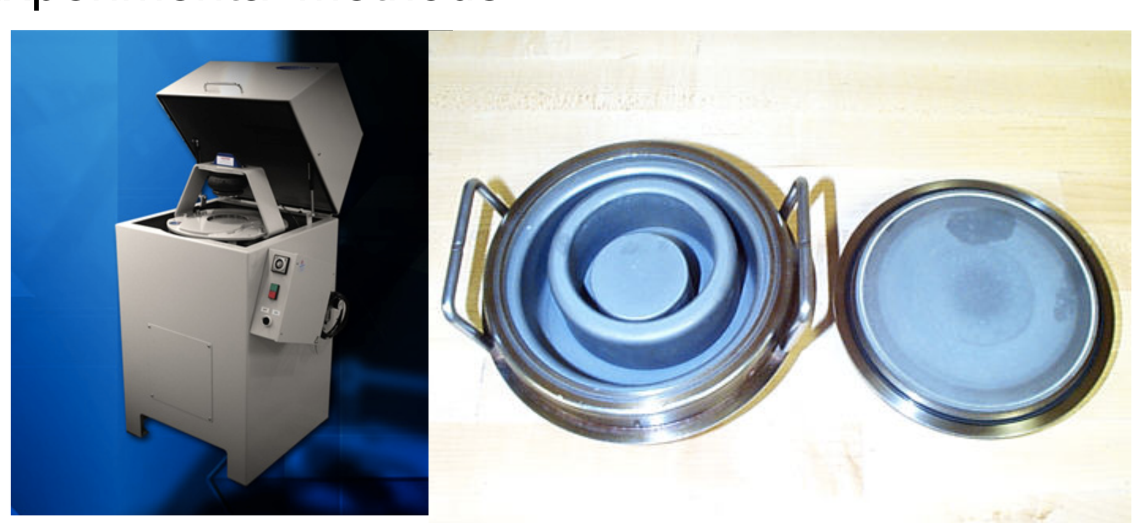

Figure 1. Standard ring & puck mill (Rocklab Pty Ltd, New Zealand)

Table 1. Fine grinding experimental parameters

Effect factor	Variable levels	Controlled condition
Moisture content	5%, 10%, 15%, 30%	Size 1/8in, loading 10g, time 2-12minutes
Feed size	Chip, 7/16in, 1/4in, 1/8in	MC10%, loading 10g, time 2-12 minutes
Feed loading	10g, 20g	MC 10%, size 1/8in, time 2-12 minutes

◆ Response evaluation

- Particle size distribution (Mastersizer 3000, Malvern instrument, UK)
- Aspect ratio distribution (ImageJ, National Institues of Health, USA)
- Morphology (Scanning electron microscopy, FEI company, USA)
- Cellulose crystallinity (Philips X'Pert MPD diffractometer)
- Specific electric energy consumption (Fluke 1735, USA)

Key Results

1. Evolution of particle morphology

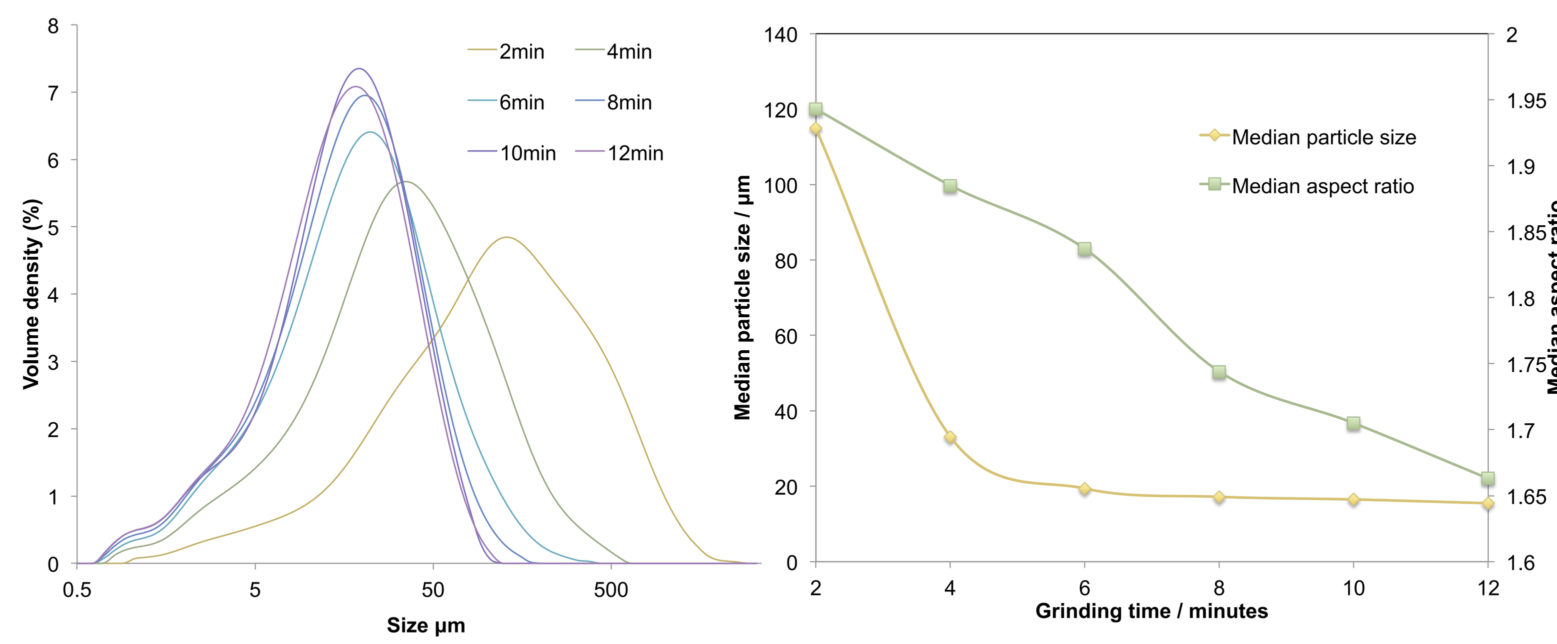

Figure 2. Characterization of ground particles in terms of particle size distribution median particle size, and median aspect ratio (Sample: feed moisture content 10%, feed size 1/8in, Loading: 10g)

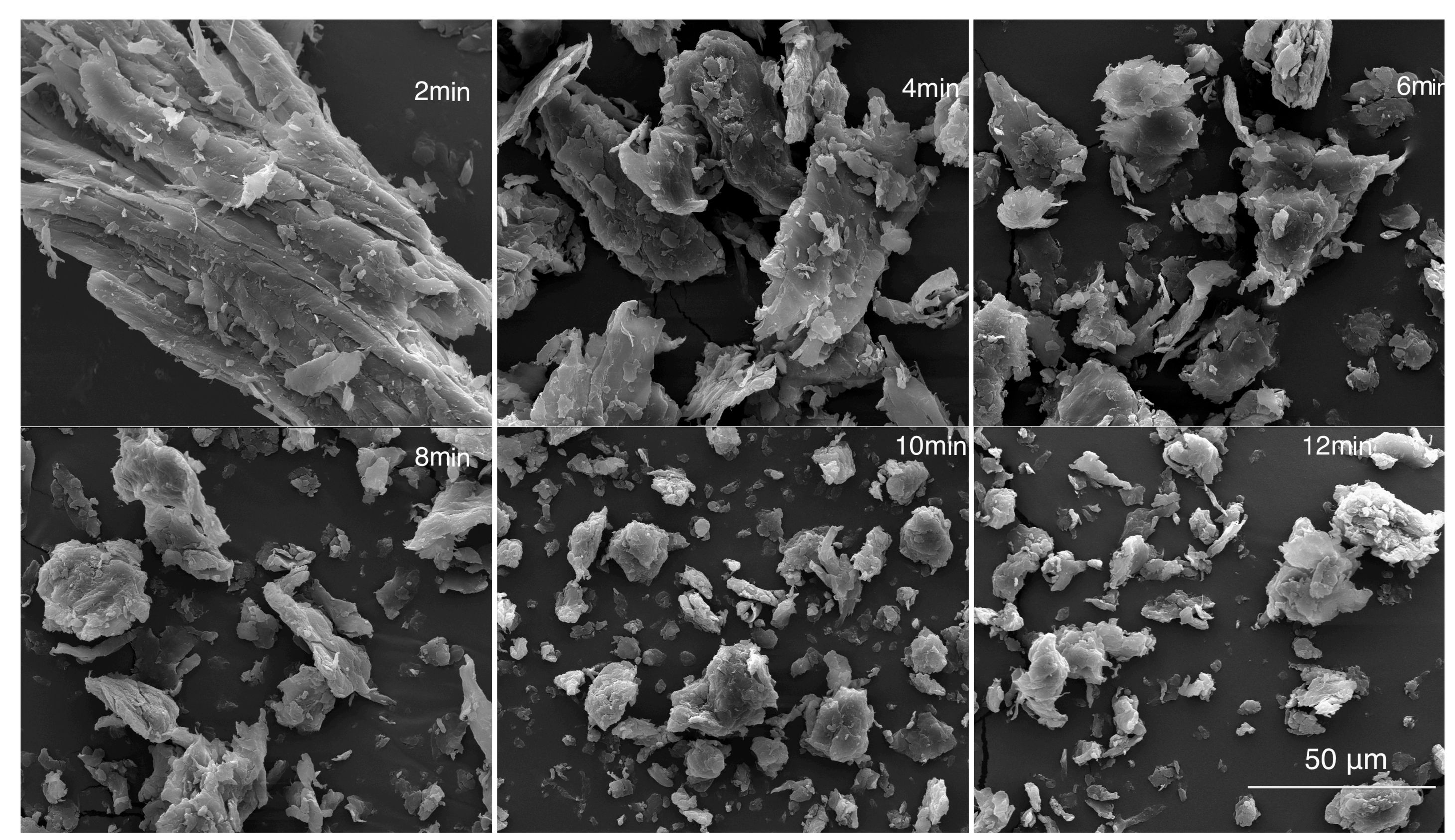

Figure 3. Scanning electron microscopic images of particles with various milling time; feed size 1/8in, moisture content 10%, charge 10g.

2. Effect of moisture content on grinding performance

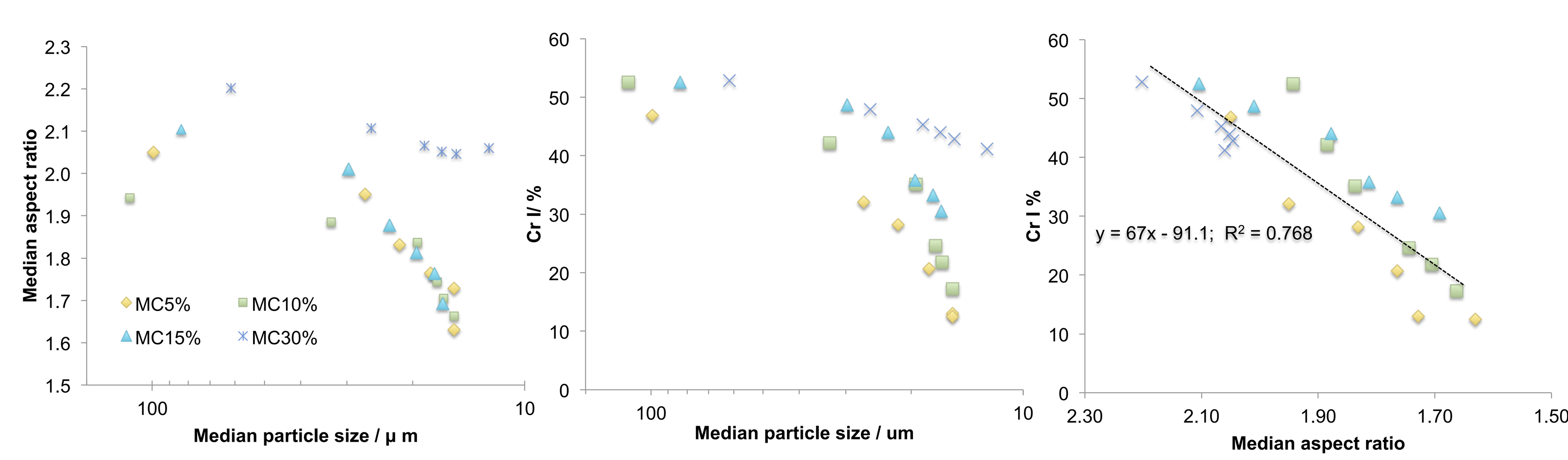

Figure 4. Effect of change in moisture content on development of physical properties of ground particles; feed size 1/8in, charge 10g.

Referance

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[2] Barakat A, de Vries H, Rouau X. 2013 Apr;134:362–73.
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3. Effect of feed size on grinding performance

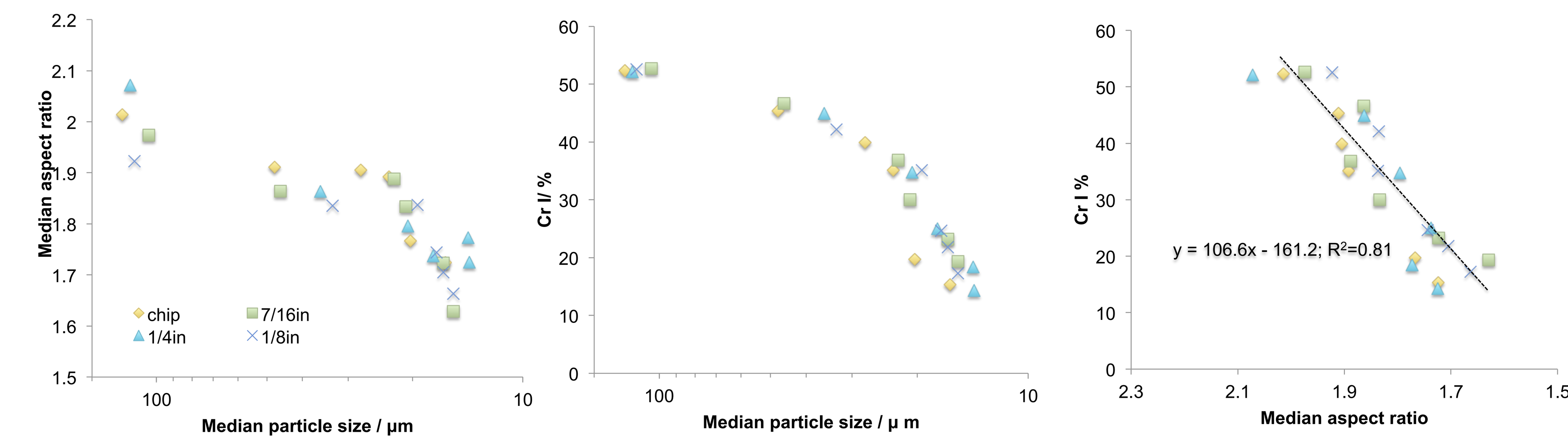

Figure 5. Effect of feed size on development of physical properties of ground particles; feed moisture content 10%, Loading: 10g)

4. Effect of feed loading on grinding performance

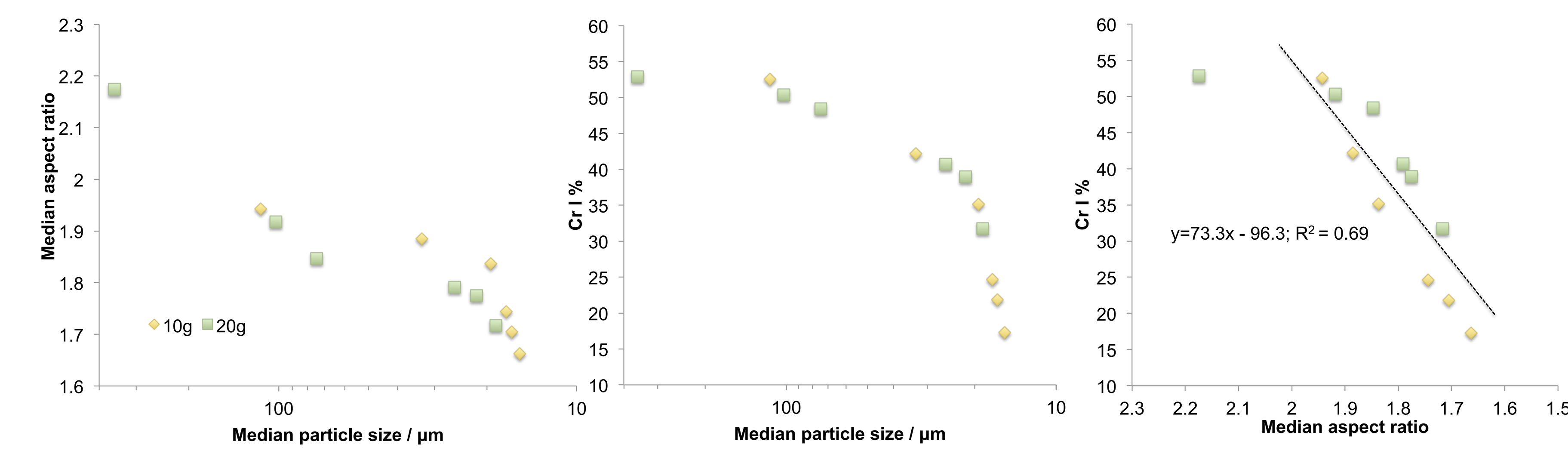

Figure 6. Effect of feed loading on development of physical properties of ground particles; feed moisture content 10%, feed size 1/8in,

5. Correlation of energy consumption and size reduction

◆ Rittinger's model $E = C(\frac{1}{x_p} - \frac{1}{x_f})$;C is a constant, x_p and x_f are 80% cumulative size of product and feed material.

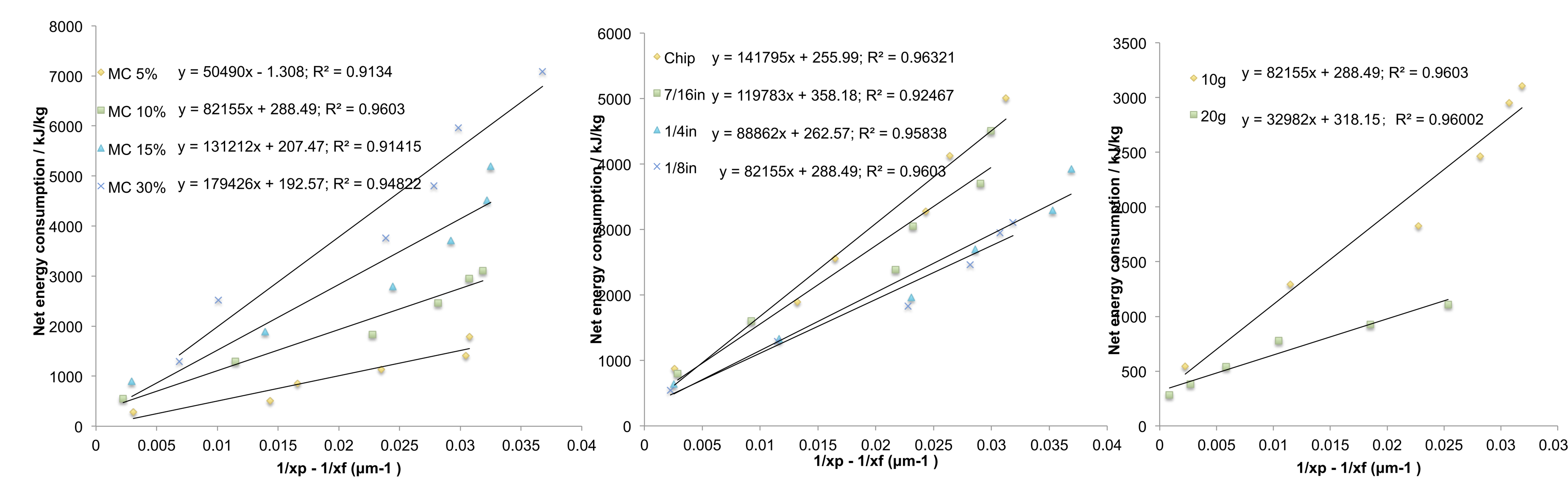

Figure 6. Correlation of specific energy consumption and product and feed size according to Rittinger's model

6. Conclusion

- Effective micronization of Douglas-fir was conducted with a vibratory ring & puck mill in several minutes.
- Moisture content was the most important factor influencing grinding behavior including particle morphology, cellulose crystallinity and grindability. There was approximate linear relationship between crystallinity index and median aspect ratio of ground particles.
- Feed and product's 80% cumulative size and specific electrical energy consumption were correlated with Rittinger's model with high determination coefficients (R^2 between 0.91 and 0.96).
- Further study is needed to standardize grinding test and parameters like work index be developed to evaluate the grindability of fibrous materials on a lab-scale, when such information would be used to design scale-up biomass grinding facilities.

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