MODELLING PARTICLE SIZE CHARACTERISTICS AND SPECIFIC ENERGY DEMAND FOR KNIFE-MILLED BEECH CHIPS AT DIFFERENT MOISTURES

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1. INTRODUCTION

- Particle size reduction increases specific surface area, being crucial for intensive mass transfer during biochemical or thermochemical biomass treatment.
- Mechanical size reduction is a costly operation that can cover up to 33 % of the total electrical demand being for a complex technology.
- Little information to quantify the effect of biomass moisture on specific energy demand during the size reduction of lignocellulosic biomass.
- Specific energy requirement typically listed as single values, poor models available.

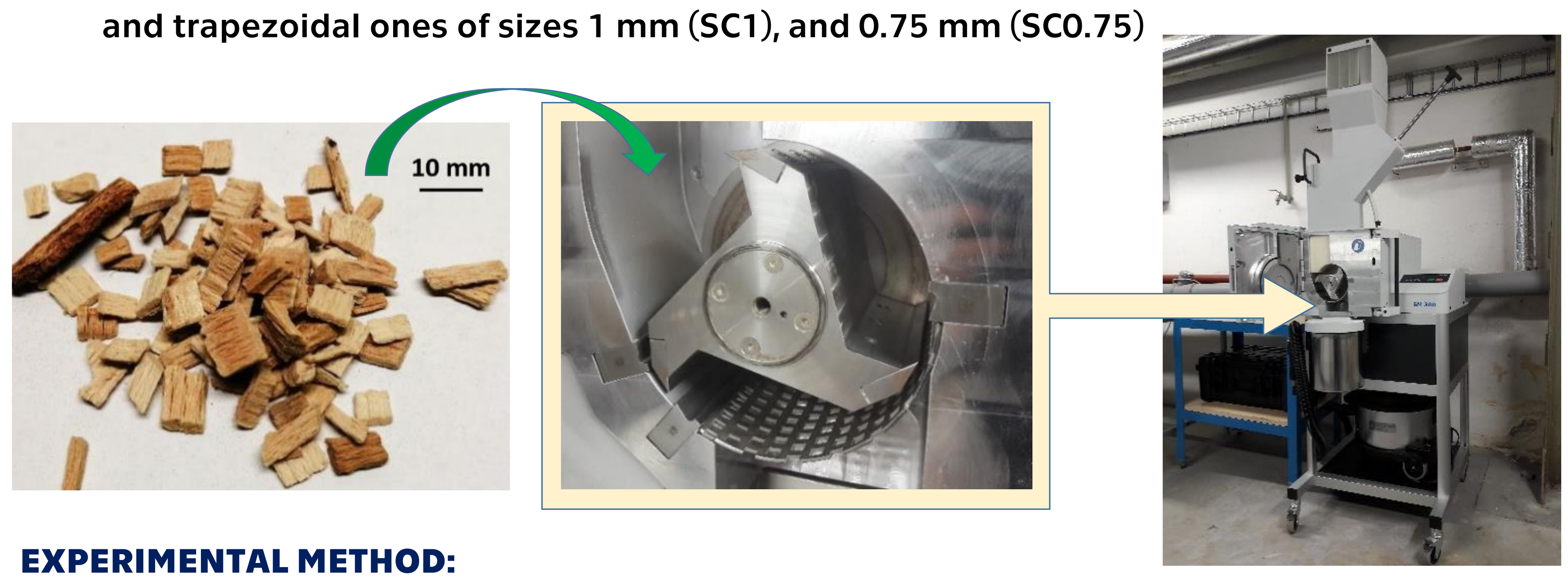
biomass	initial/final particle size (mm)	moisture (wt %)	machine	specific energy requirement (kWh t^{-1})	reference
hard wood	22.4/1.6	4-7	knife mill	130.0	Cadoche and Lopéz [1]
	22.4/2.5	4-7		80.0	
	22.4/6.3	4-7		25.0	
	19.05/1.6	6	hammer mill	130.0	Himmel et al. [2]
	19.05/2.5	6		80.0	
	19.05/6.4	6		27.0	
rye straw	22.4/1.6	6.9	hammer mill	27.1	
	22.4/1.6	12		42.8	
corn stover	22.4/3.2	4-7	knife mill	20.0	Cadoche and Lopéz [1]

[1] L. Cadoche, G.D. López, Biological Wastes 1989, 30, 153
[2] M. Himmel, M. Tucker, J. Baker, Biotech. Bioeng. 1985, 15, 39.

AIMS:
1. To experimentally identify the effect of biomass characteristics *(moisture, initial particle size)* and knife mill variables *(screen size)* on specific energy requirement.
2. To define and calibrate a model that allows predicting specific energy requirement for knife milling of beech chips at different moistures.

2. MATERIALS AND METHODS

- beech chips with moistures 0.50 ± 0.03 wt %, 7.50 ± 0.01 wt %, 15.9 ± 0.1 wt %
- the laboratory knife mill SM300 equipped with a three-bladed rotor
  - the peripheral speed of revolution 20.4 m s^{-1} (3000 min^{-1})
  - screen sieves of square openings with the sizes of 6 mm (SC6), 4 mm (SC4), 2 mm (SC2), and trapezoidal ones of sizes 1 mm (SC1), and 0.75 mm (SC0.75)



EXPERIMENTAL METHOD:
- The sample was initially analysed in its weight and particle size distribution.
- The milling of the sample under the given process variables of the knife mill.
- The milled sample was finally weighed and analysed in particle size distribution.

PARTICLE SIZE ANALYSIS:
- The standard screen sieve method for biomass according to ASABE S424.1.
- The Rosin-Rammler-Sperling-Bennet (RRSB) model regressed experimentally reached cumulative mass perceptual proportions of individual runs.
- The characteristic particle size D_{50} was calculated for each sample before and after milling.

$$D_F = D_P \cdot [-ln(1-F)]^{\frac{1}{n}}$$

F (wt %) - cumulative mass fraction smaller than a given characteristic particle size D_F (mm)
D_P (mm) - characteristic particle size at the cumulative mass fraction 63.2 wt %
n (-) - index of polydispersity

$$e = \frac{\int_0^t P_{AM}\,dt - \int_0^t P_{AI}\,dt}{m}$$

e (W s t^{-1}) – specific energy requirement
P_{AM} (W) - active power during biomass milling at a given time t (s)
P_{AI} (W) - active power during the idle state at the same time t (s)
m (kg) - weight of treated sample

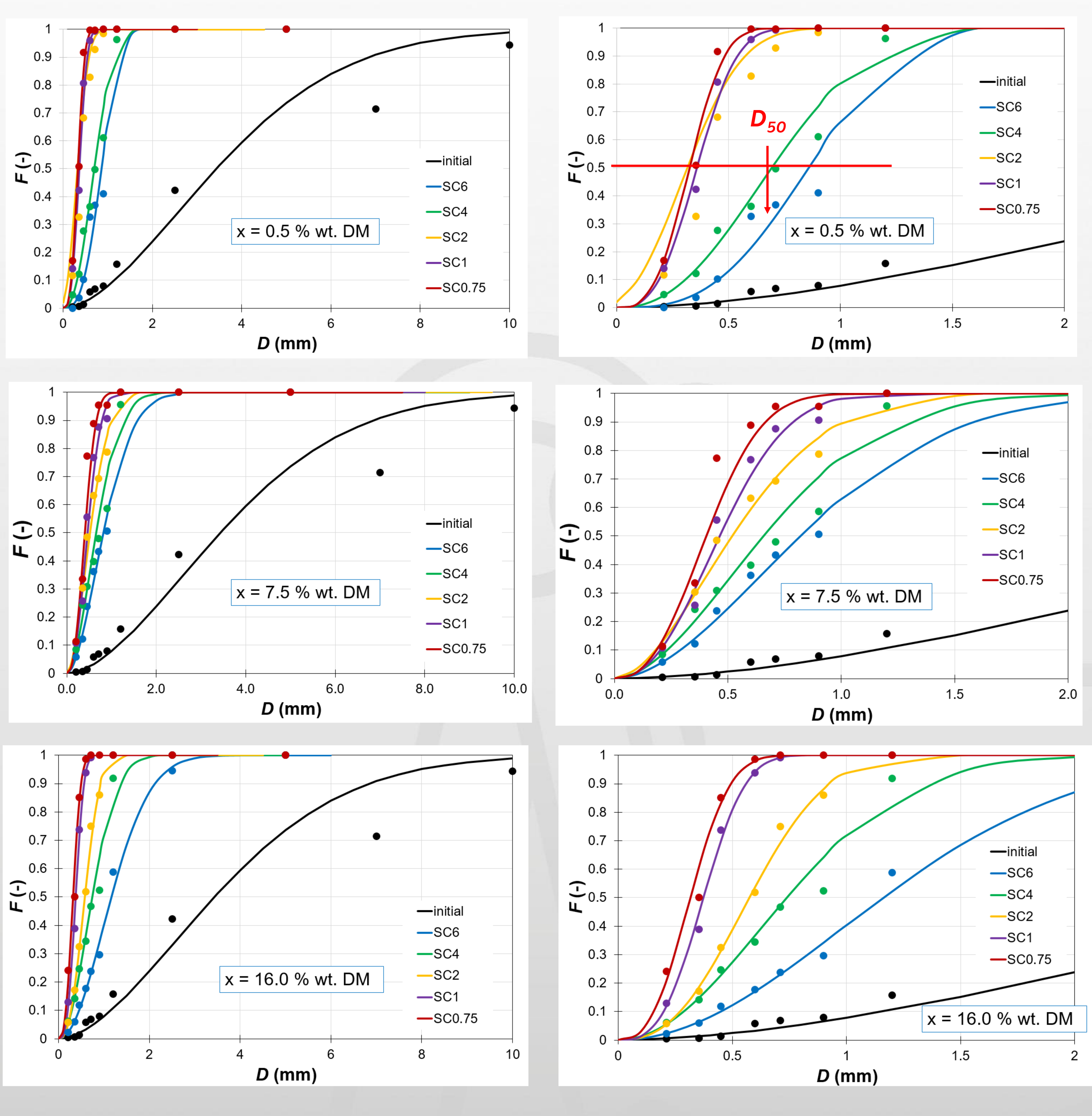
IDENTIFYING SPECIFIC ENERGY REQUIREMENT
- Measuring active power in time-related a milled amount of sample.
- The active state = active power during the milling of the given sample.
- The idle state = no material was reduced in size -> passive resistances.

3. RESULTS AND DISCUSSION

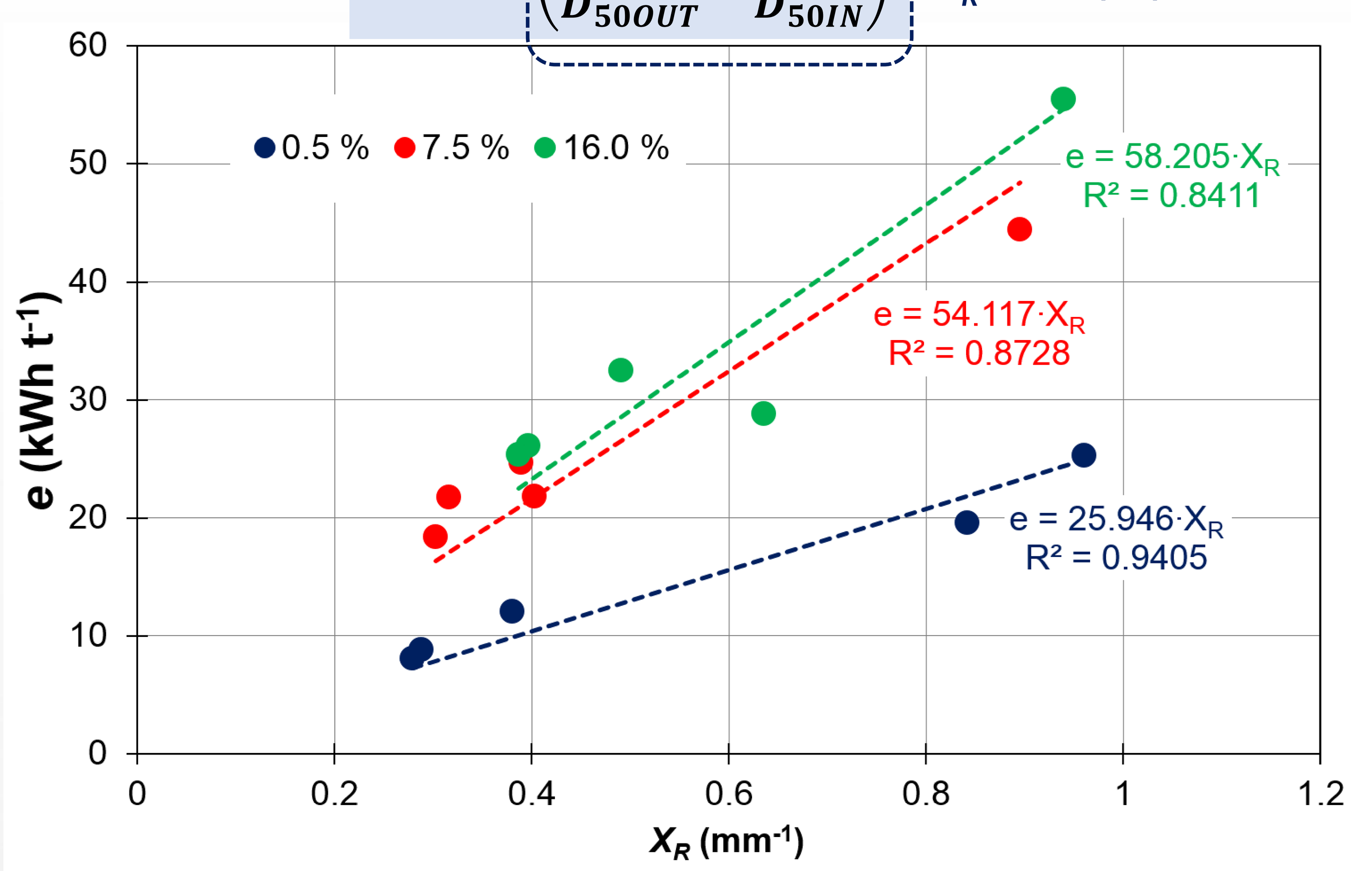
- Each experimental run characterised by the weight of sample *m* processed at time t, energy demand *e* and particle size characteristics.
- The gained experimental results of screen sieve analysis regressed by RRSB model.
- The characteristic parameters of RRSB models were identified.

	characteristics of particle size for individual runs					
	initial	SC6	SC4	SC2	SC1	SC0.75
x = 0.5 % wt.						
D_P (mm)	4.24	0.97	0.82	0.48	0.40	0.37
n (-)	1.73	2.96	2.31	2.48	2.95	3.06
D_{50} (mm)	3.09	0.85	0.69	0.41	0.36	0.32
x = 7.5 % wt.						
D_P (mm)	4.24	1.00	0.80	0.64	0.55	0.47
n (-)	1.73	1.82	1.81	2.74	2.27	2.42
D_{50} (mm)	3.09	0.82	0.66	0.56	0.46	0.40
x = 16.0 % wt.						
D_P (mm)	4.24	1.39	0.89	0.66	0.42	0.36
n (-)	1.73	1.98	1.98	2.50	2.97	2.68
D_{50} (mm)	3.09	1.04	0.73	0.57	0.37	0.31

point – experimental value, curve – fitted RRSB model



Rittinger law $e = C_R \cdot \left(\frac{1}{D_{50OUT}} - \frac{1}{D_{50IN}}\right) X_R$ — energy required for size reduction is directly proportional to the increase in particle surface



- The Rittinger model precisely fits the experimental data.
- The slope of the model given by C_R value increases with an increase in wood chips moisture *X*.

- The Rittinger constant is affected by strength yield of beech chips that vary with moisture.
- The higher moisture, the higher Rittinger constant.
  - *If biomass is dry, the only shear is used to reduce particles in size.*
  - *If biomass moisture is increasing, biomass particles become elastic. -> mutual effect of shear and attrition -> higher energy demand.*

4. CONCLUSION

- The effect of wood chips moisture on specific energy requirements was studied.
- The wood chips evinced brittle behaviour.
- The Rittinger law was found to precisely fit the experimentally identified values of specific energy requirement in dependence on particle size characteristics and biomass moisture.
- The Rittinger constant is significantly affected moisture content.
- This model was defined predicting specific energy demand on biomass moisture and particle sizes with the precision R^2 = 0.84.

$$e = C_R \cdot \left(\frac{1}{D_{50OUT}} - \frac{1}{D_{50IN}}\right)$$

C_R (X=0.5 %) = 25.95 kWh mm t^{-1}
C_R (X=7.5 %) = 54.12 kWh mm t^{-1}
C_R (X=15.9 %) = 58.20 kWh mm t^{-1}

Validity ranges: *wood chips, moisture of 0.5-15.9 wt %, initial particle size D_{50IN} of 0.36-3.09 mm, final particle size D_{50OUT} of 0.31-1.04 mm, and size reduction in knife mill with biomass flowrates 25-128 kg h^{-1} m^{-1} of the total length of installed blades in pair, peripheral rotor velocity 20.4 m s^{-1}.*

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