EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research, Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS

Visegrad Fund

THE EFFECT OF MOISTURE ON SPECIFIC ENERGY DEMAND FOR KNIFE-MILLED WHEAT STRAW

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INTRODUCTION

- Mechanical size reduction = INITIAL STEP of waste treatment technologies.

WHY TO DO IT?

- \+ An increase of specific surface, bulk density.
- \+ Increasing efficiency of subsequent treatment.
- \+ Shearing or defibering of biomass particles.
- \+ Reduction in degree of polycrystalinity.
- \+ Easier handling, reducing transportation cost.

SOME LIMITATIONS?

- \- High energy-demanded.
- \- Biomass behaviour.
- \- Technical limits of commercial size reduction machines.

TECHNOLOGY	TARGETED PARTICLE SIZE
Pelleting briquetting	< 6 mm
Pulverized combustion	< 1 mm
Pyrolysis	0.25-2.00 mm
Fluid bed gasification	0.12-10.00 mm
Fermentation	0.03-10 mm
Lignocellulosic distillery	0.5-3.0 mm

MECHANICAL ENERGY NEED TO REDUCE PARTICLES FROM NATIVE/INITIAL TO A TARGETED PARTICLE SIZE BETWEEN MILL WORKING TOOLS

[1] Hendriks A.T.W.M., Zeeman G., 2009, Pretreatment to enhance the digestibility of lignocellulosic biomass, Bioresource Technology, 100, 10-18.
[2] Hoque M., Sokhansanj S., Naimi L., Bi X., Lim J., 2007, Review and analysis of performance and productivity of size reduction equipment for fibrous materials. ASABE Annual International Meeting, Minneapolis, Minnesota.
[3] Oyedeji O., Gitman P., Qu J., Webb E., 2020, Understanding the impact of lignocellulosic biomass variability on the size reduction process: A review, Webb, ACS Sustainable Chemistry and Engineering, 8, 2327-2343.
[4] Miao Z., Grift T.E., Hansen A.C., Ting K.C., 2011, Energy requirement for comminution of biomass in relation to particle physical properties, Industrial Crops and Products, 33, 504-513.

DEFINING AIMS AND NOVELTY

- Specific energy requirement listed as single values.
- A little information served regarding modelling of energy demand on biomass characteristics.
  - regression curves - **power, exponential, polynomic or linear functions**
  - conventional models - **Bond, Rittinger, or Kick comminution laws**

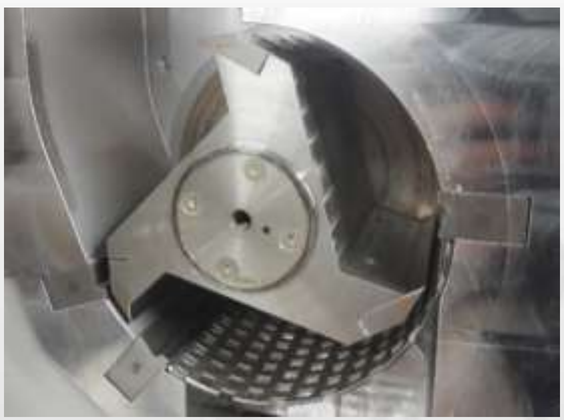
$$\frac{de}{dD} = -C \cdot D^{-r}$$

AIMS:

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

MATERIAL AND MACHINE

- Wheat straw with moistures 3.1 wt %, 8.1 wt %, 22.9 wt %
- the laboratory knife mill SM300 equipped with a three linear-bladed rotor
  - **rotor speeds of 10.2 m s^{-1} (1500 rpm) and 20.4 m s^{-1} (3000 rpm)**
  - **screen sieves of openings 10 - 6 - 4 – 2 -1 - 0.75 mm**



EXPERIMENTAL LAYOUT

➢ Each experimental run characterized by particle size characteristic before/after milling and by specific energy demand.

Particle size characteristics:

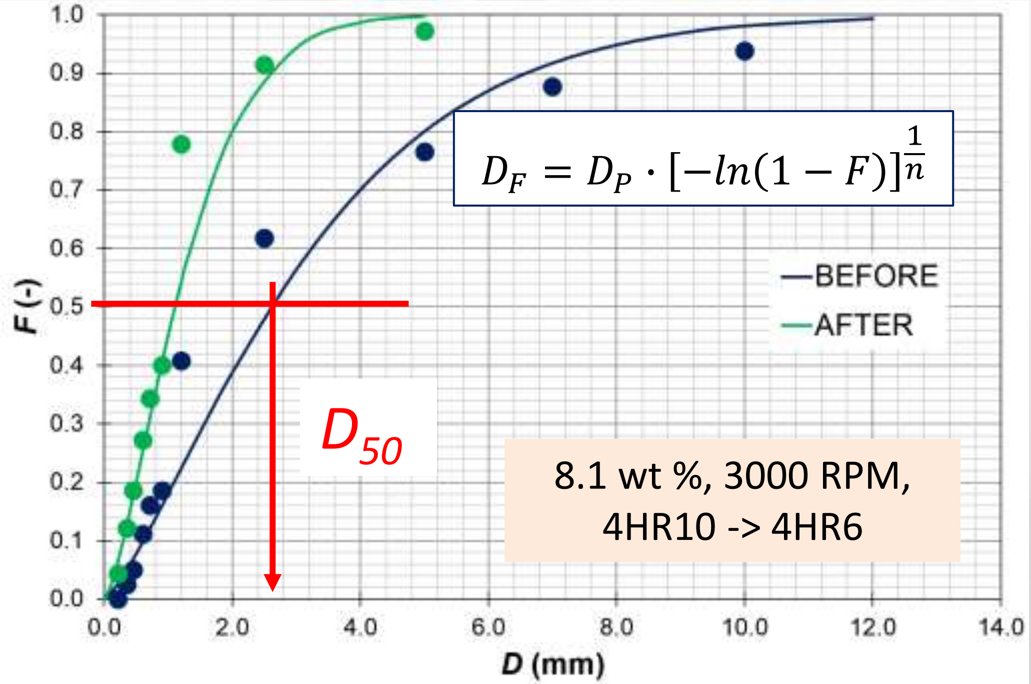
- Screen sieve analysis by the ASABE standard S424.1.
- Applying RRSB model.
- Identifying D_{50} value.

Specific energy demand:

- Analysing active power during milling and iddle state by power analyser in period 1 s.

$$e = \frac{1}{m} \cdot \left(\int_0^t P_{AM}\, dt - \int_0^t P_{AI}\, dt \right)$$

POINT = EXPERIMENT, CURVE = RRSB MODEL



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

8.1 wt %, 3000 RPM, 4HR10 -> 4HR6

RESULTS AND DISCUSSION

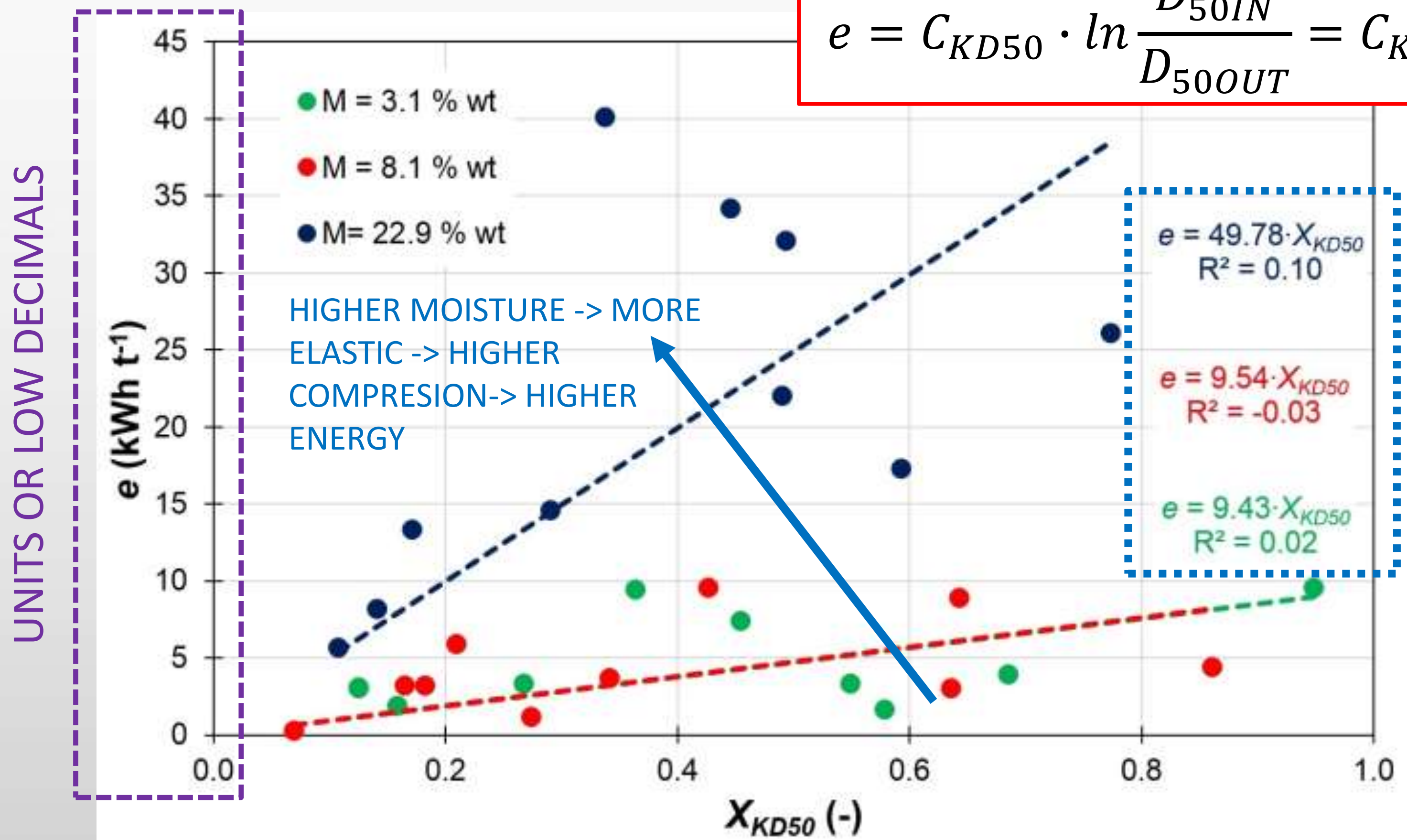
KICK THEORY:

- energy need to ensure a particle's elastic deformation followed by its crack

r= 1

$$\frac{de}{dD} = -C \cdot D^{-r}$$

$$e = C_{KD50} \cdot ln \frac{D_{50IN}}{D_{50OUT}} = C_{KD50} \cdot X_{KD50}$$



POOR PRECISION

NOT APPLICABLE

RESULTS AND DISCUSSION

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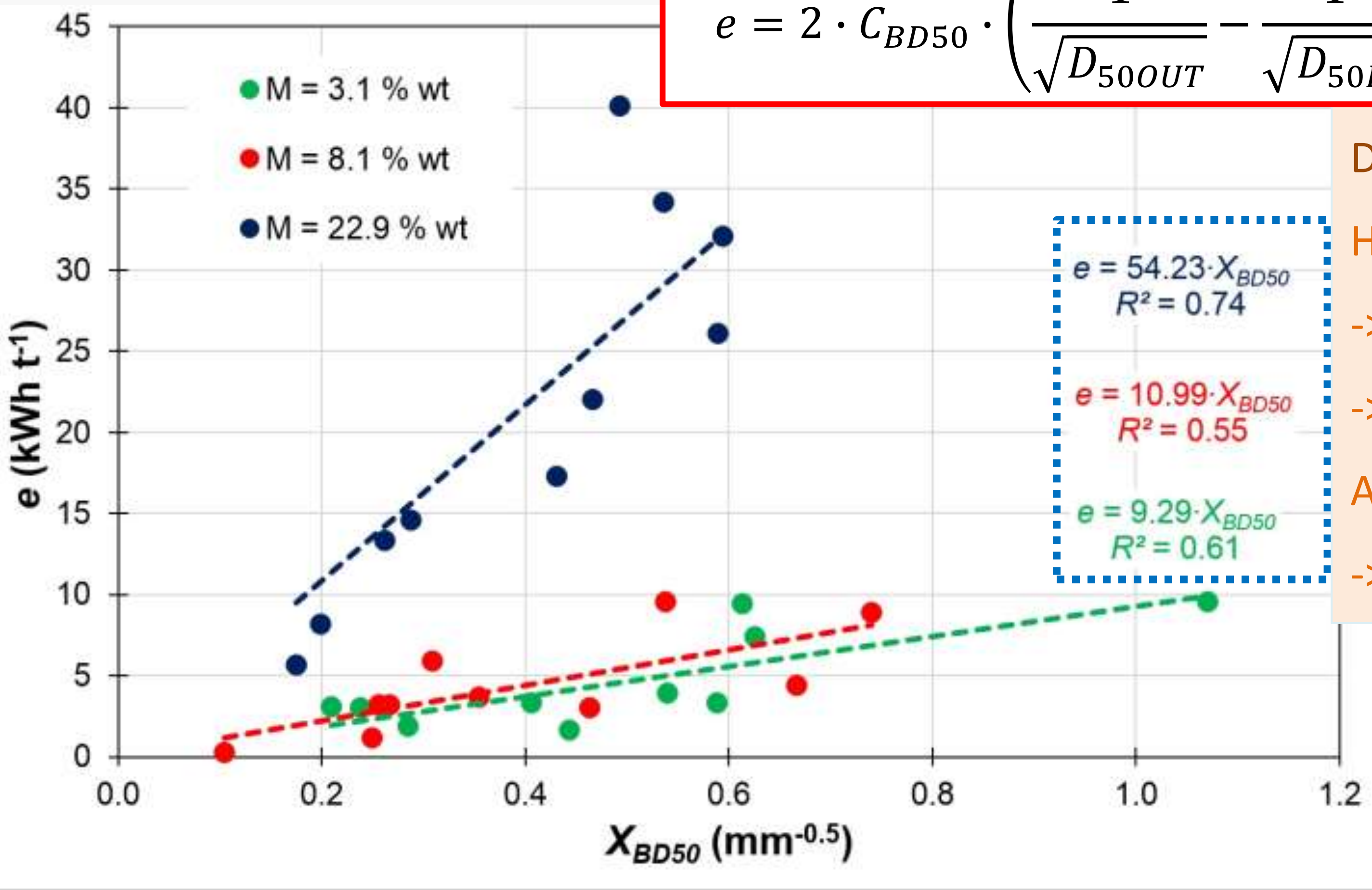
BOND THEORY:

- energy needed for crack propagation is proportional to the new crack length

r= 1.5

$$\frac{de}{dD} = -C \cdot D^{-r}$$

$$e = 2 \cdot C_{BD50} \cdot \left(\frac{1}{\sqrt{D_{50OUT}}} - \frac{1}{\sqrt{D_{50IN}}} \right) = C_{BD50} \cdot X_{BD50}$$



DRY STRAW = CUTTING

HIGHER MOISTURE

-> MORE ELASTIC

-> CUTTING, SHEARING AND TEARING

-> HIGHER ENERGY

GOOD PRECISION

APPLICABLE ???

RESULTS AND DISCUSSION

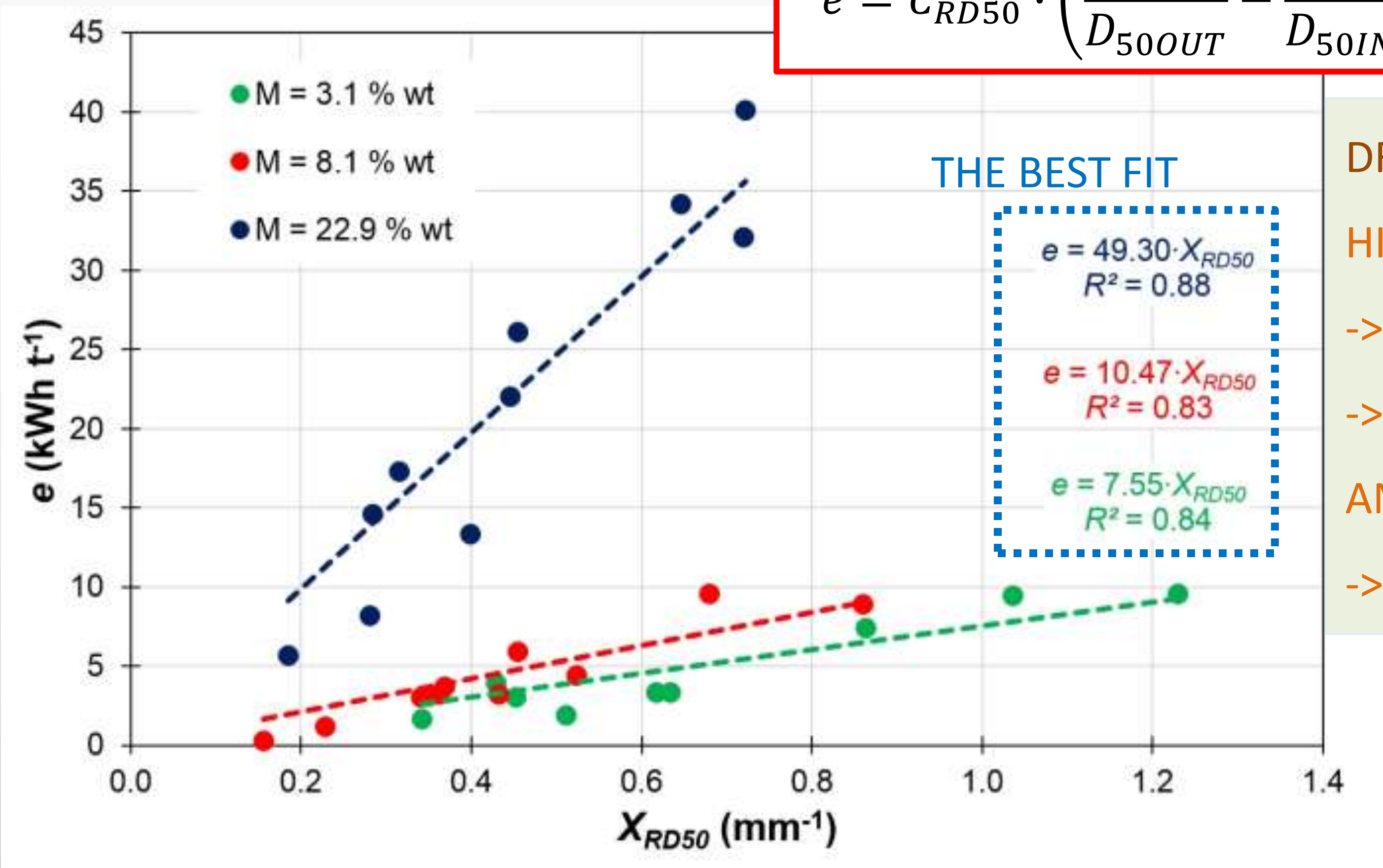
RITTINGER THEORY:

- energy directly proportional to the particle surface increase

r= 2

$$\frac{de}{dD} = -C \cdot D^{-r}$$

$$e = C_{RD50} \cdot \left(\frac{1}{D_{50OUT}} - \frac{1}{D_{50IN}} \right) = C_{RD50} \cdot X_{RD50}$$



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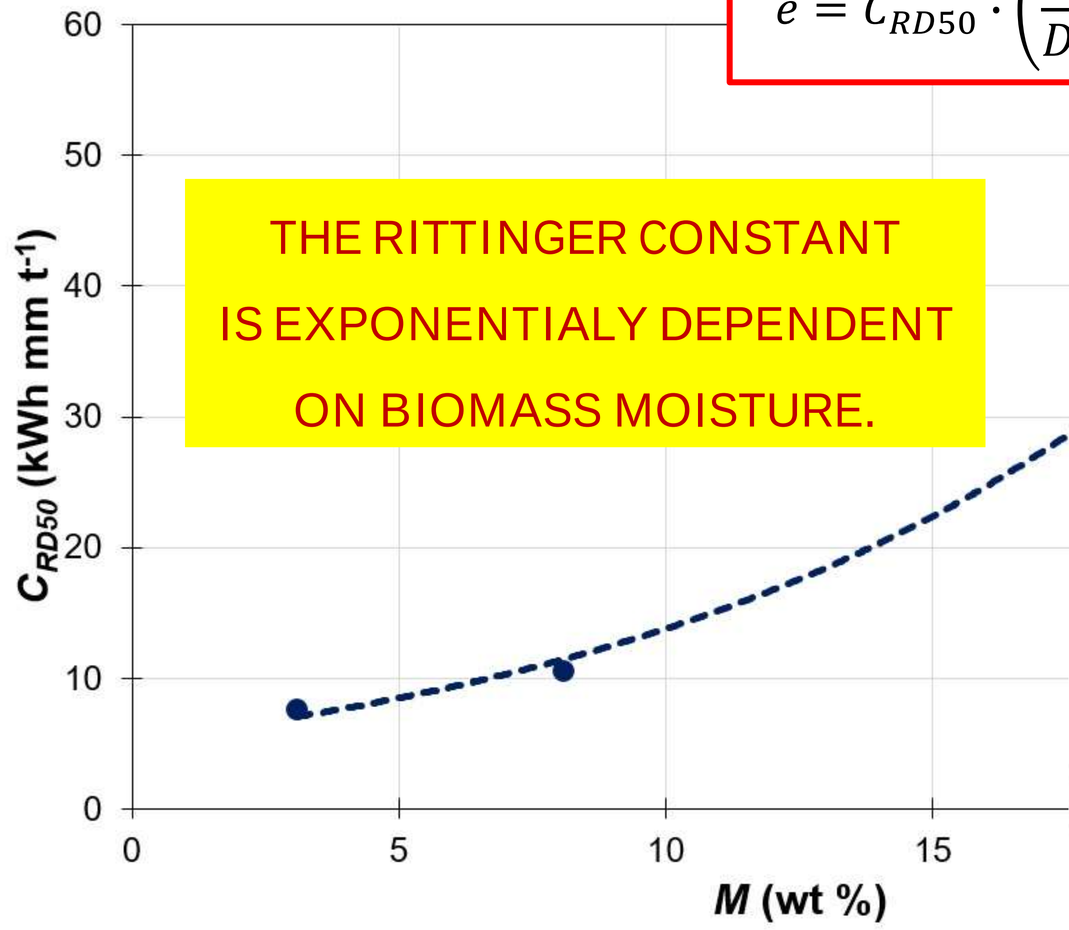
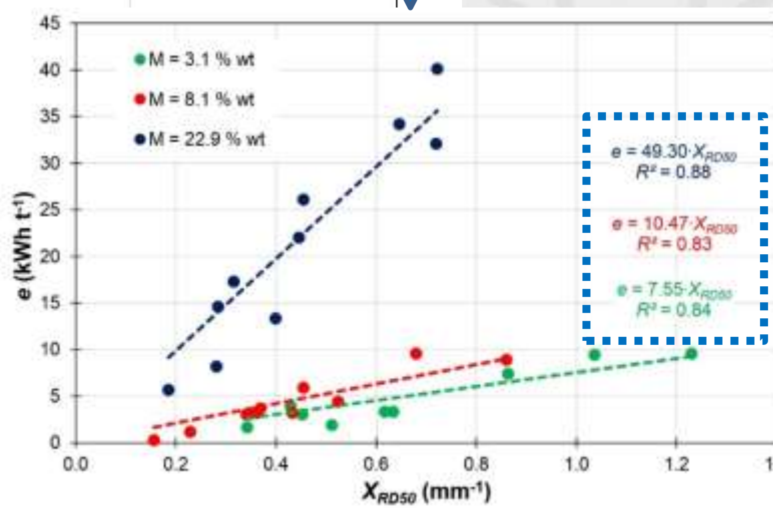


THE RITTINGER CONSTANT
IS EXPONENTIALY DEPENDENT
ON BIOMASS MOISTURE.

EFFECT OF MOISTURE ???

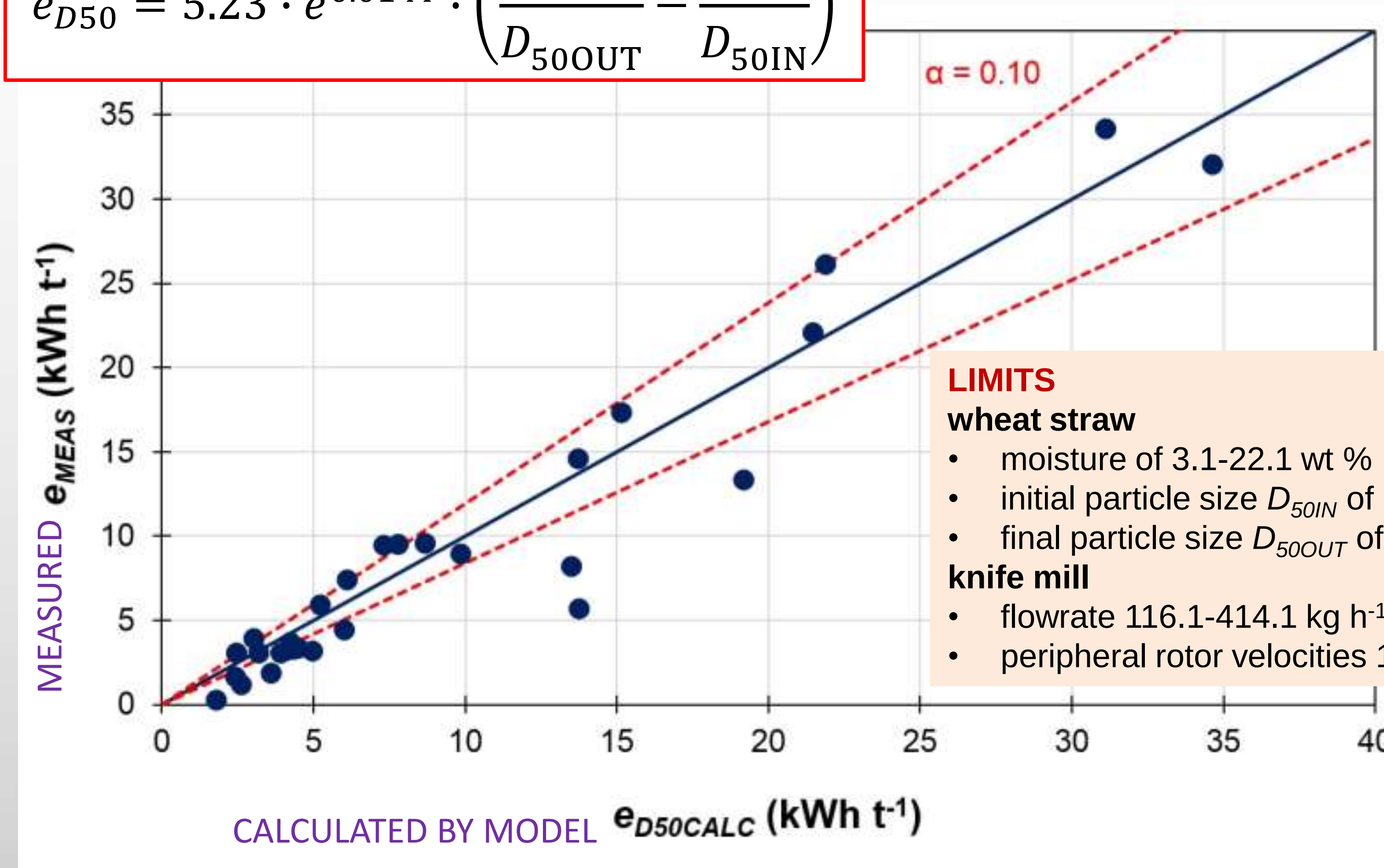


RESULTS AND DISCUSSION

DEFINING PREDICTION MODEL:

$$e_{D50} = 5.23 \cdot e^{0.01 \cdot M} \cdot \left(\frac{1}{D_{50OUT}} - \frac{1}{D_{50IN}} \right)$$

the precision expressed by the confidence intervals in the confidence level of α = 0.1



LIMITS

wheat straw

- moisture of 3.1-22.1 wt %
- initial particle size D_{50IN} of 0.29-2.61 mm
- final particle size D_{50OUT} of 0.25 – 1.41 mm

knife mill

- flowrate 116.1-414.1 kg h^{-1} m^{-1}
- peripheral rotor velocities 10.2-20.4 m s^{-1}.

CONLUSIONS

- The effect of moisture on specific energy demand for knife milled wheat straw experimentally quantified
- The specific energy requirement ranges in units or lower tents of kWh t^{-1}.
- Comminution laws were tested to define mutual relations among specific energy demand, particle size characteristics and biomass moisture.

MESSAGE TO TAKE HOME:

- The Rittinger comminution law showed the highest precision.
- The value of the Rittinger constant was power law dependent on moisture content.

$$e_{D50} = 5.23 \cdot e^{0.01 \cdot M} \cdot \left(\frac{1}{D_{50OUT}} - \frac{1}{D_{50IN}}\right)$$

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