Fine grinding, a refresher

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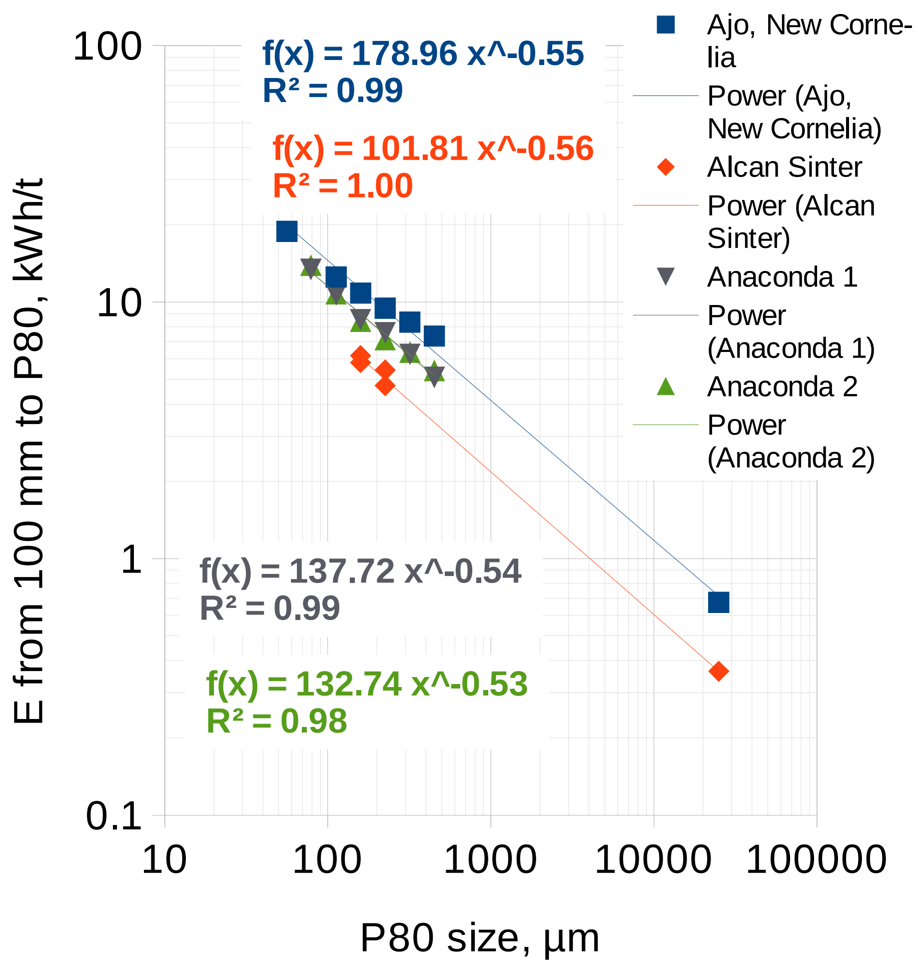
Purpose

- Metallurgists use models as tools, and
- each tool is suited to a particular task.
- Fine grinding requires different tools to “regular” grinding.

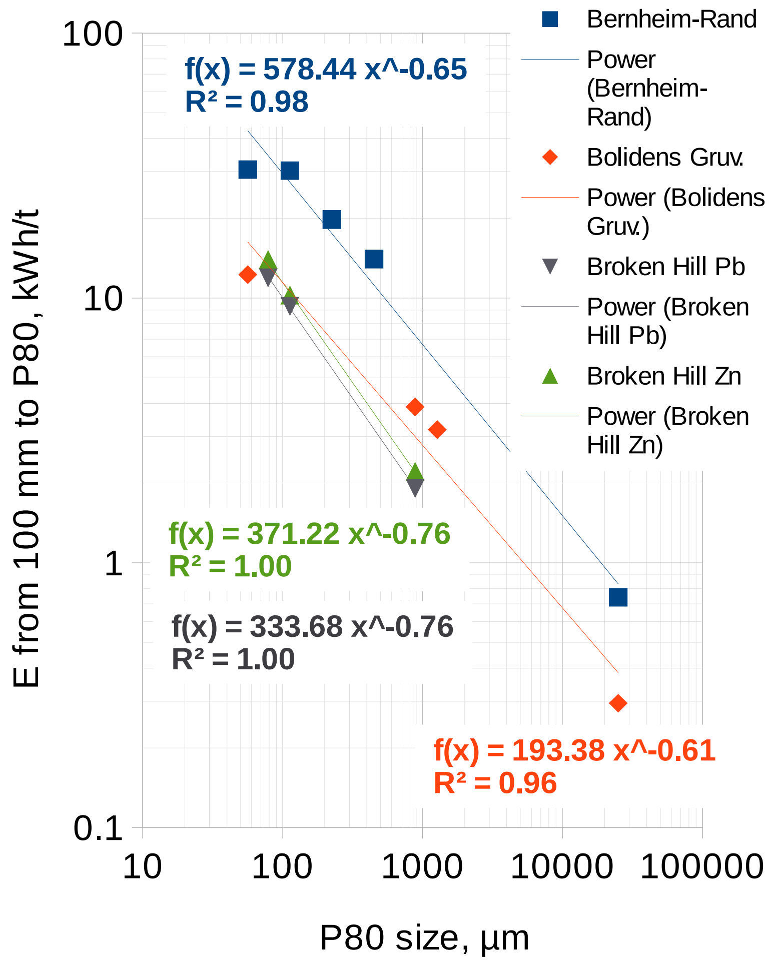
Bond work index



- Commonly used model that describes conventional grinding.
- Based on fixed exponent of -0.5.
- Empirically fit to data collected in the 1930’s and 1940’s.

Bond work index

- Did not fit all data and often has issues at upper and lower size boundaries.
- Fudges, kludges and bodges are applied to “finer” grinding, Eg. below 75 µm.



The bigger picture

- Bond's model is one of a larger family of power-based models.
- Other examples:
  - Von Rittinger's model
    $E = a\, X^{-1}$
  - Kick's model
    $E \propto X_1 / X_0$

- Overall model

$$E = a \times X^{-b}$$

where:

  - E is specific energy consumption, kWh/t
  - X is particle 80% passing size, µm
  - *a* and *b* are fitted parameters.

The following may be disturbing to some viewers.

User discretion is advised.

The bigger picture

- Many power-based models are solutions to a single equation:

$$\frac{dE}{dx} = K \times X^{-c}$$

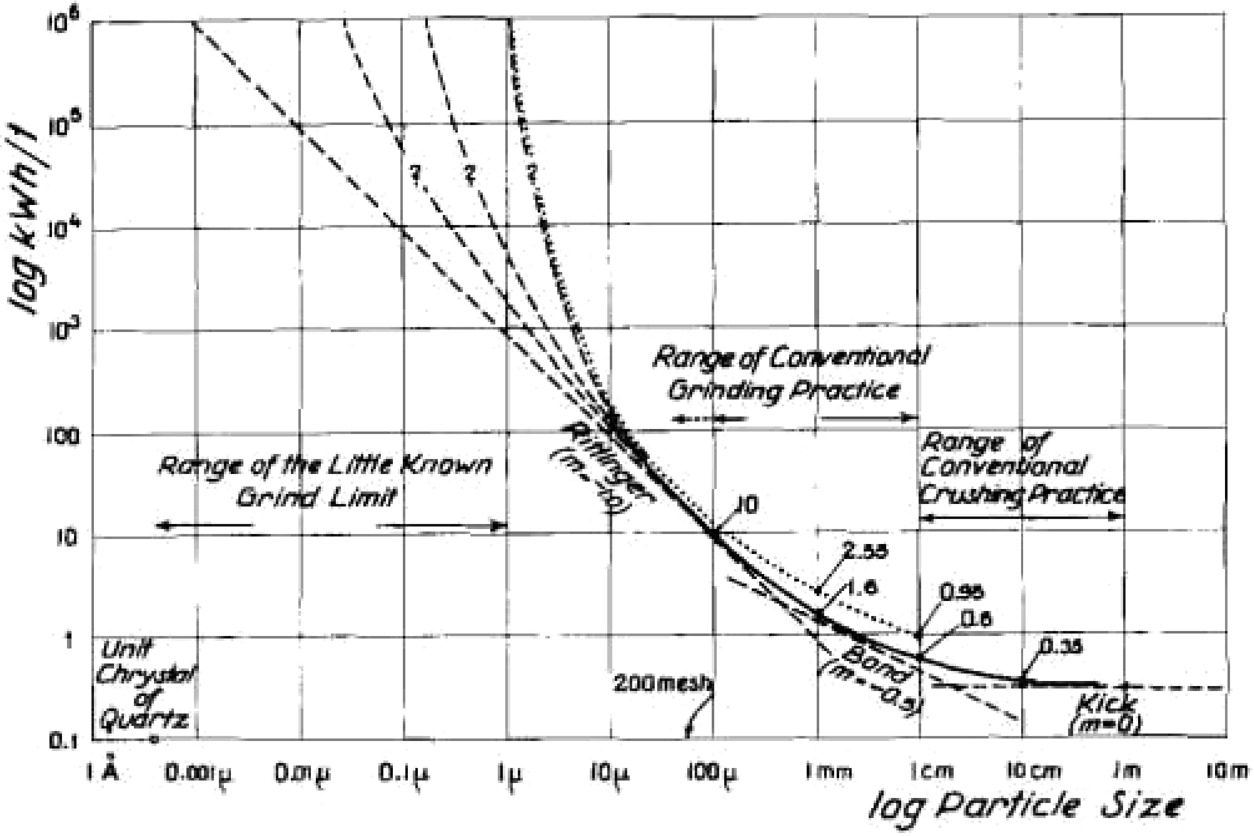
where:

  - *K* and *c* are ore-specific fitted constants

- One integrated form: $$E = a \times \left(X_1^{-b} - X_0^{-b} \right)$$

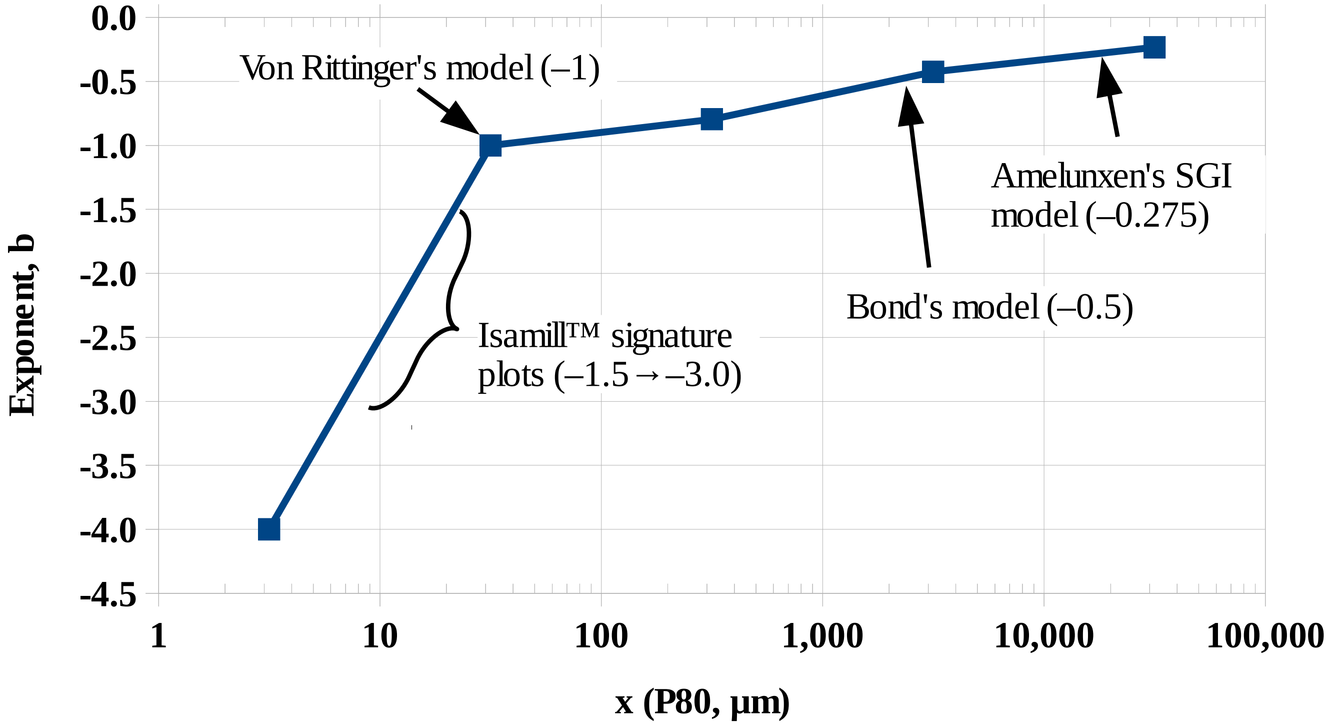
Hukki's Conjecture

- R. Hukki did experiments measuring specific energy consumption across a range of sizes



Hukki’s Conjuecture

- The exponent changes with particle size.
- A fixed exponent is suitable for limited size ranges.



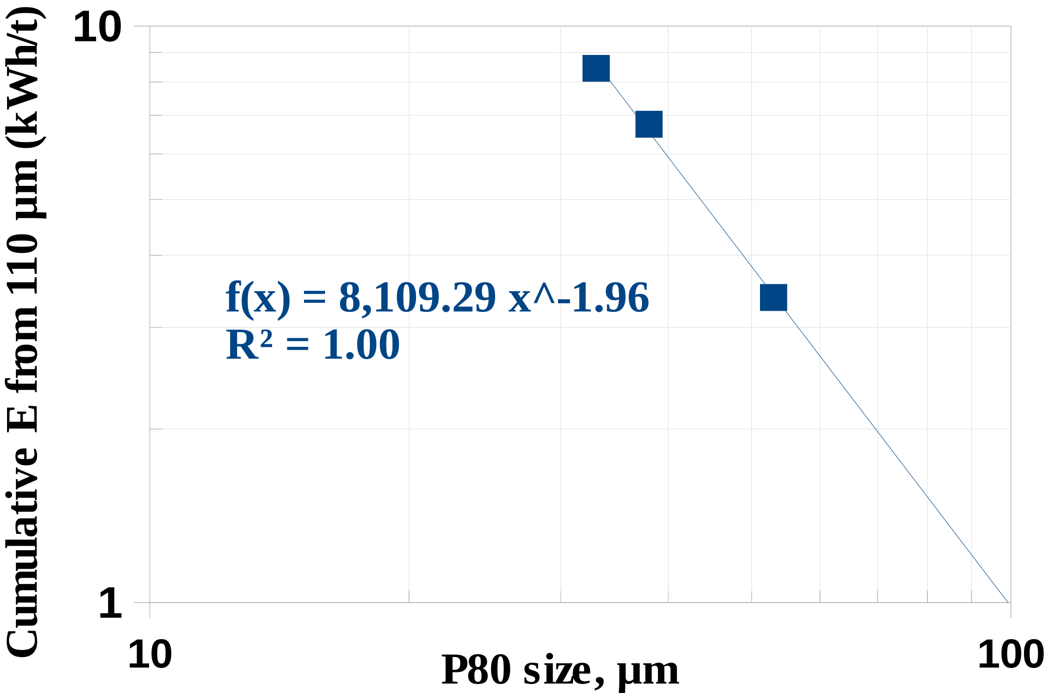
Fine grinding

- The definition of “fine grinding” is somewhat material-specific. Propose the definition be based on “where Bond’s model no longer applies”.
- Generally translates to sizes below 100 µm, becomes more acute below 75 µm.

Option 1: Use a variable exponent

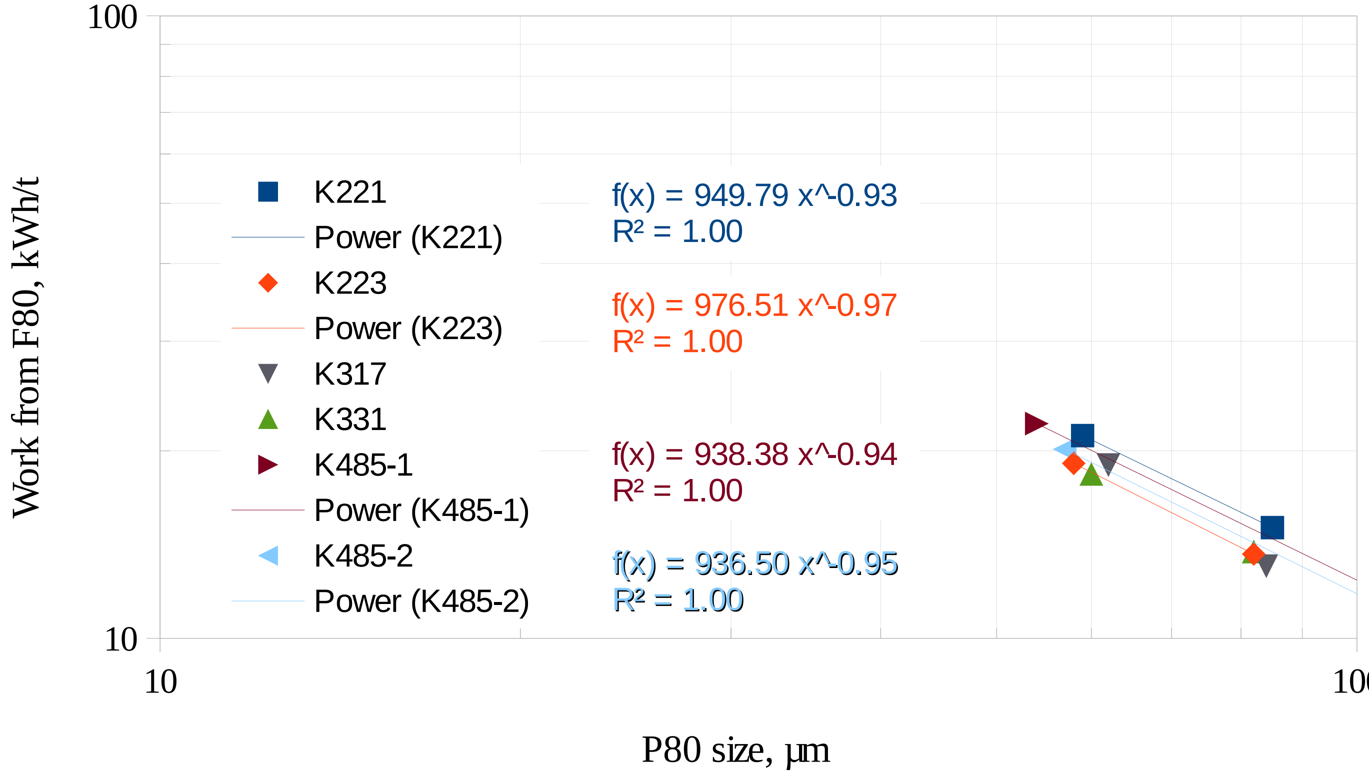
- Jar mill test from Merriam et al, CMP 2015

x, µm	E, kWh/t
110	0
53	3.38
38	6.75
33	8.44



Option 2: use exponent -1

- Von Rittinger's model generally works better in 50 µm to 100 µm size range.



Fitting data from Aureus Mining (2012) Bond ball mill tests on gold ore

Option 3: Use material-specific exponents

Material	**Exponent**	**Equation**	**Size range**
Gold ore (hydrothermal, greenstone, silicate hosted)	-0.9	$E = C\,x^{-0.9}$	500 → 40 µm
Lead-zinc ore (massive sulphide)	-1.0 -1.4	$E = C\,x^{-1.0}$ $E = C\,x^{-1.4}$	65 → 45 µm 45 → 5 µm
Porphyry ore (silica, feldspars, minor sulphides)	-0.5	$E = C\,x^{-0.5}$	235 → 78 µm
Copper rougher concentrate (chalcopyrite and pyrite)	-1.5	$E = C\,x^{-1.5}$	110→33 µm
Pyrite concentrate	-2.0	$E = C\,x^{-2.0}$	40 → 8 µm
Base metal matte (copper, nickel)	-1.5	$E = C\,x^{-1.5}$	300 → 60 µm
Iron ore (hematite, magnetite)	-0.7 -1.8	$E = C\,x^{-0.7}$ $E = C\,x^{-1.8}$	160→75 µm 75 → 15 µm
Zinc concentrate (Gao et al, 2007)	-1.2	$E = C\,x^{-1.2}$	20 → 5 µm

Comments

- Assumes that specific energy consumption is material-specific and size-specific. Any “efficient” equipment should give similar results.
  - Equipment vendors may have different opinions.
- Fitting to plant data will give an equipment-specific model. Other classes of equipment may be more efficient.
  - Grinding media size, for example, affects fine grinding efficiency.

Conclusions

- Stop using Bond models for fine grinding.
  - Use specific energy consumption & size in NI43-101 reports.
- Use an appropriate model for fine grinding.