Effect of moisture types on fuel flowability

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Flex Flores RFCS project - a step towards a more sustainable energy generation
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Presentation outline

- Flowability and moisture types
  - Moisture definitions
  - Standards to determine moisture
  - Properties affecting coal flowability
- Experimental study in Flex Flores project
  - Coals of different rank
  - Laboratory equipment and method
  - Results
- Conclusions

Flowability and moisture types

Flowability of coal

- Flowability = transportability
  - Handling and transport of fuel depends on its capacity to be moved

- Direct impact on availability and reliable operation of a power plant

Flowability and moisture types

Moisture definitions

- Moisture (M), especially surface moisture, is commonly recognized as a key factor affecting handling and transportability of a coal
- Terminology used to specify moisture types:
  - total, as-received, equilibrium, inherent, free, air-dry loss, residual, pore, surface…
- Reviewed standards:
  - ISO: determination 589 and 5068
  - ASTM: terminology D121, D2013; and determination D3302, D3173, D1412

Flowability and moisture types

ISO standards for moisture determination in coals

ISO 589 Total moisture in hard coals	ISO 5068 Total moisture in brown coals & lignites
• One-stage method: Crushed sample is dried in either nitrogen, or air at 105-110 °C **Total M** is calculated from the loss in mass • Two-stage method: 1. sample is dried in air at ambient T or at 30-40 °C = **free M** 2*. crushed air-dried sample is dried in nitrogen at 105-110 °C = **residual M** **Total M = free M + residual M**	• One-stage method: Crushed sample is dried in nitrogen at 105-110 °C **Total M** is calculated from the loss in mass • Two-stage method: 1. sample is dried in air at ambient T or at 30-40 °C = **air-dry loss M** 2. crushed air-dried sample is dried in nitrogen at 105-110 °C = **residual M** **Total M = air-dry loss M + residual M**

*each standard address its suitability limitations depending weather coals are susceptible to oxidation
! Important to note that standards define max particle size of sample in each step

Free moisture = Air- dry loss moisture; surface moisture not mentined

as by ISO 589 and ISO 5068

Flowability and moisture types

ASTM standards for moisture determination in coal and coke

ASTM D121

Terminology – Coal and Coke

- **Total M = inherent M + surface M**
  - inherent M = bed M ≈ pore M
  - surface M = excess M = extraneous M = **free M**
  - Standardized methods for determination of inherent M and surface M do not exist > approximation
- Equilibrium M determined according to D1412
- **air-dry loss**, the loss in mass, expressed … resulting from each air-drying stage …
- **residual M** – "Residual moisture is neither a standard state nor a characteristic property of a coal. Air drying only removes water that can evaporate at or near ambient laboratory conditions leaving in the coal water that will not evaporate at those conditions"

ASTM D3302

Total moisture in coal and coke

- Two-stage method:
  1. Drying sample in air at ambient T, or in oven at 10-15°C, ≤10°C for subbituminous and lignite = **air-dry loss M**
  2. crushed air-dried sample is dried in nitrogen at 105-110 °C = **residual M**

  Total moisture = air-dry loss + residual moisture
- "The repeatability and reproducibility limits given in the standard apply only to coals without **free (surface) moisture** in the gross sample before preparation of 2.36-mm sieve-size subsamples"

! Important to note that standards define max particle size of sample in each step

Free M = Surface M ≠ Air- dry loss M

Inherent M ≠ Residual M

Equilibrium M (ASTM D1412) = Inherent M, high rank coals

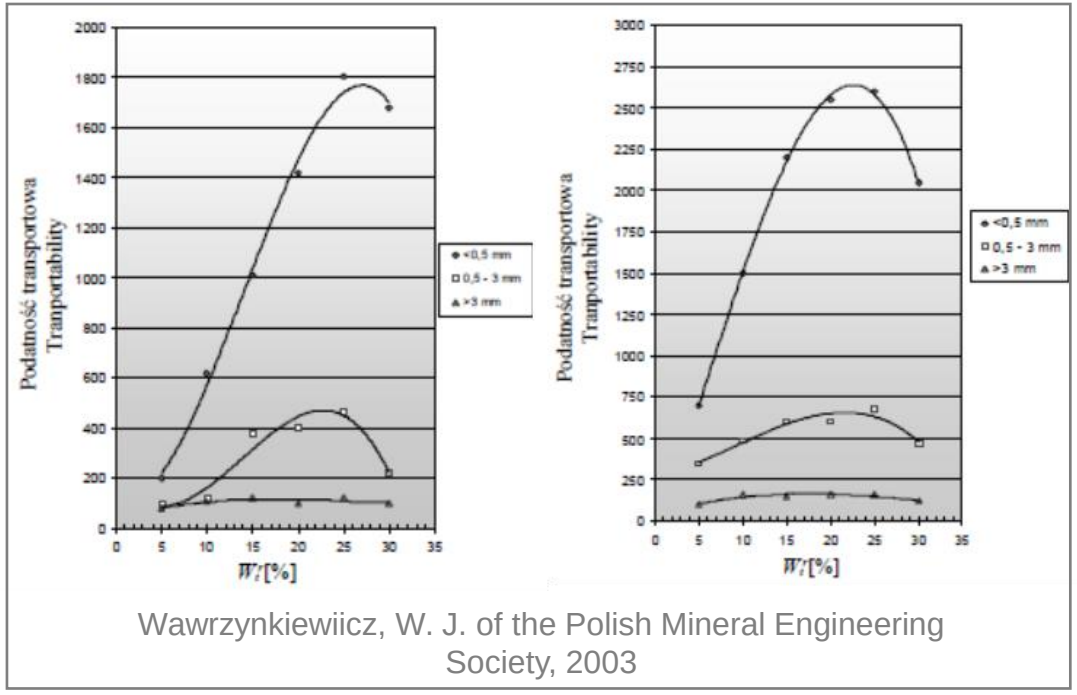
Equilibrium moisture (ASTM D1412) < Inherent M, low rank coals

Surface M ≈ total M (ASTM D3302) – equilibrium M (ASTM D1412)

Flowability and moisture types

Effect of moisture on coal flowability, literature

- Moisture effect on flowability is interconnected with other factors, such as:
  - Particle size distribution
  - Mineral composition, especially clay minerals
  - Consolidation pressure and time
  - Temperature

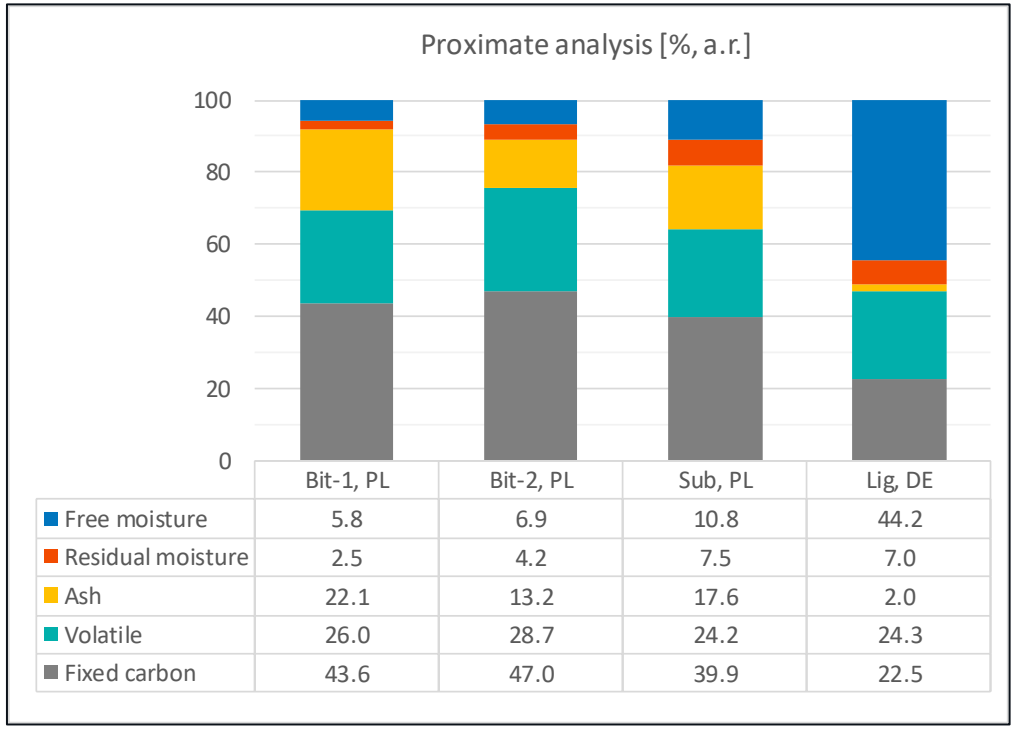


Wawrzynkiewiicz, W. J. of the Polish Mineral Engineering Society, 2003

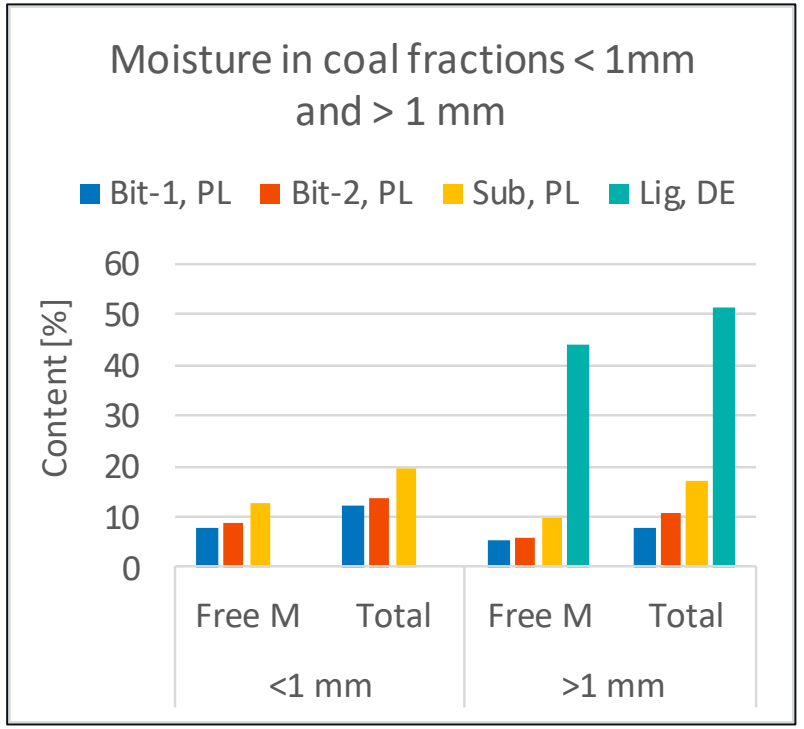
- Wawrzynkiewiicz, W., 2003. For two studied coals:
  - Almost no effect of moisture when particles > 3mm
  - Highest moisture effect for particles <0.5 mm
  - Moisture shows bell-shaped effect on transportability; inflection point is at ~25% moisture

Experimental study

Coal proximate analyses



	Bit-1, PL	Bit-2, PL	Sub, PL	Lig, DE
Free moisture	5.8	6.9	10.8	44.2
Residual moisture	2.5	4.2	7.5	7.0
Ash	22.1	13.2	17.6	2.0
Volatile	26.0	28.7	24.2	24.3
Fixed carbon	43.6	47.0	39.9	22.5

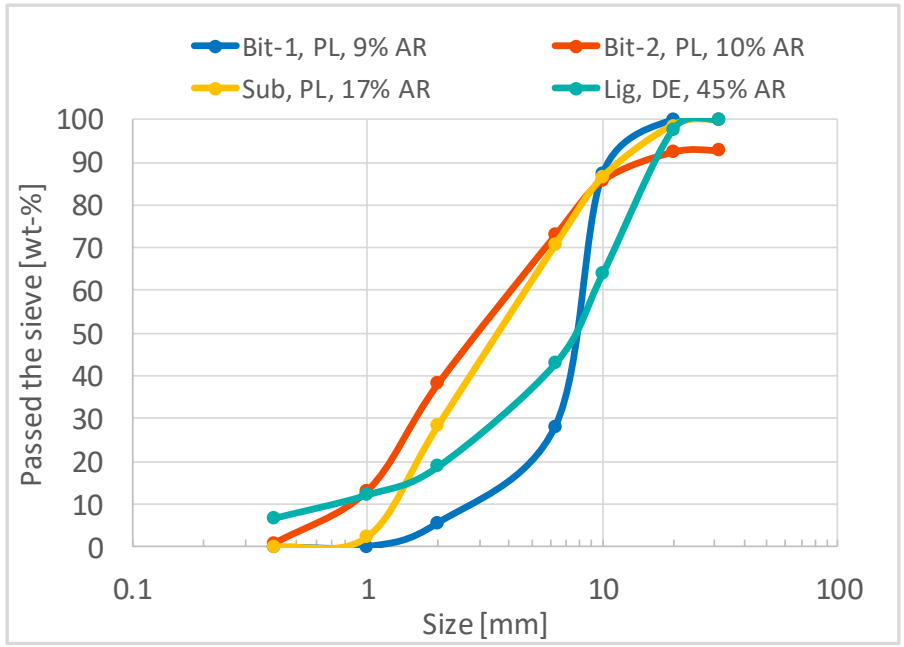


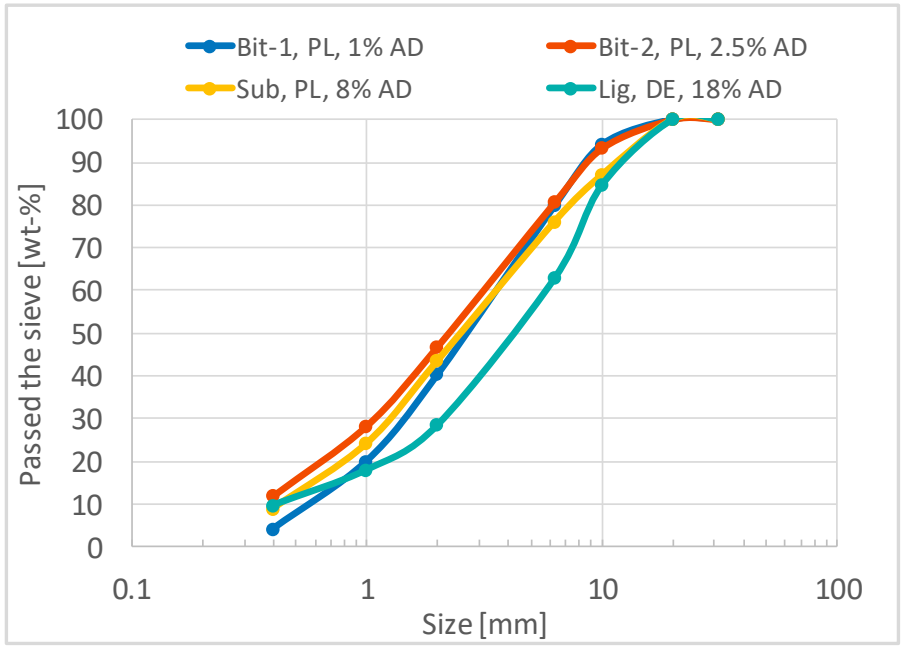
*Moisture determined according ISO standards: Total M = Free M + Residual M

- Moisture increases in following order: bituminous < subbituminous <lignite, however, share of free moisture does not always follow coal rank order
- Moisture, free and total, is higher in particle size fraction < 1mm

Experimental study

Particle size distribution of tested coals





- Particle size distribution was varing in broad range especailly for AR coals

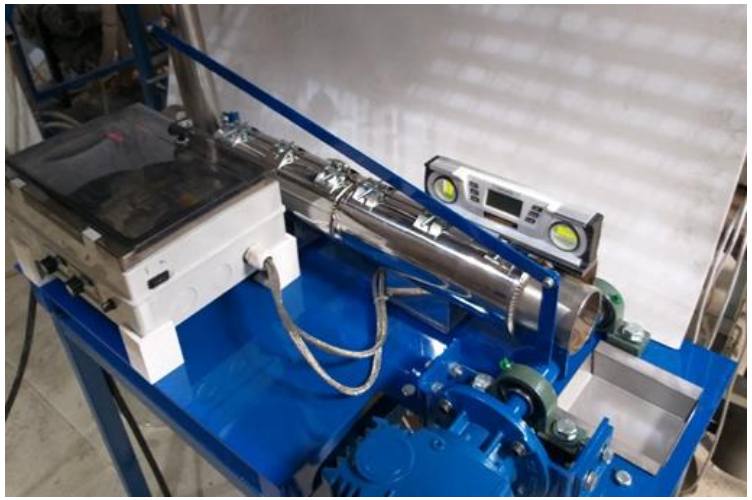
Experimental study

Laboratory equipment and method

- Experimental equipment designed at Sumitomo SHI FW (SFW)
  - Comprises stainless steel pipe, so-called slope pipe, with adjustable:
    - Angle up to 60°,
    - Temperature up to 400 °C.
- For each coal type, several moisture contents were tested:
  a) as received (AR)
  b) air-dried (AD)
  c) 2-4 water-doped samples in which moisture is higher than in a).
- Procedures for flowability test:

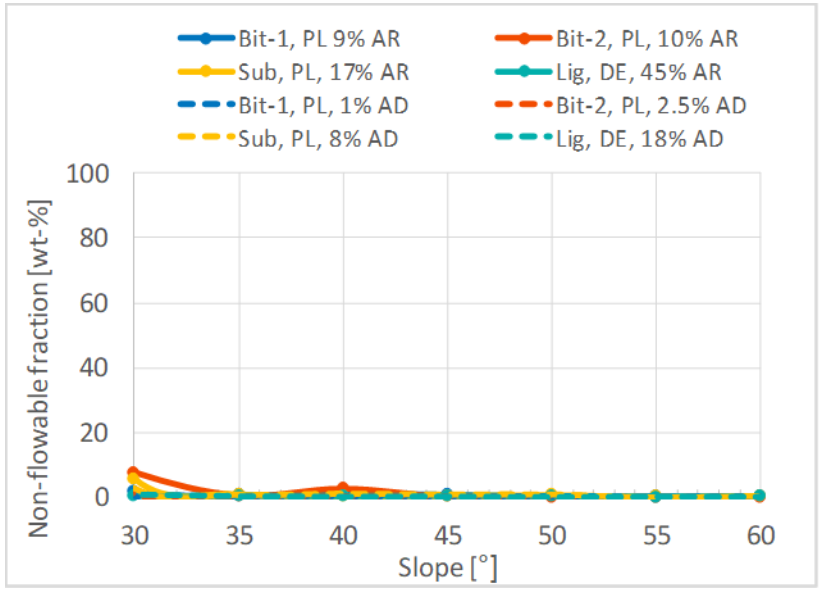
I. Slope test – Method #1 : the angle when the flow starts, and the angle when the full flow occurs

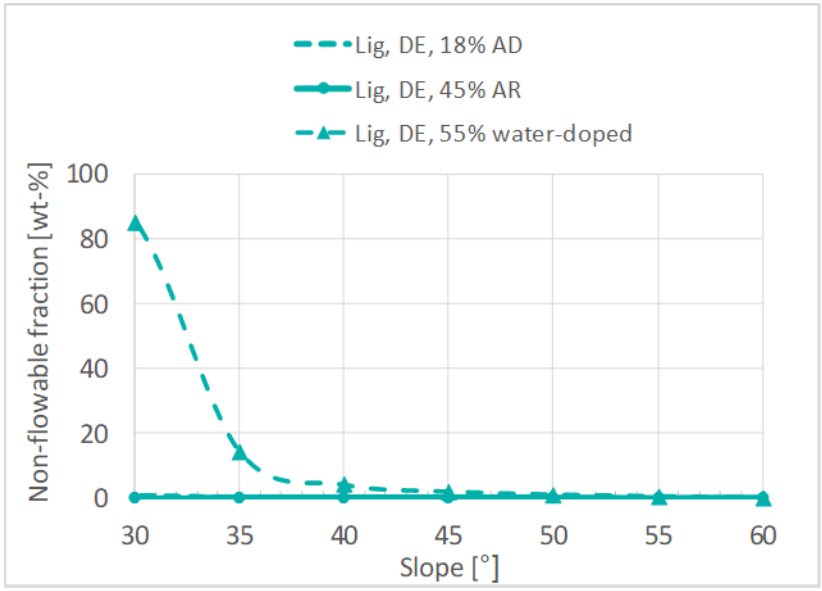
II. Drop test – Method #2: share of accumulated fuel fraction @slope angle



Experimental study

Flowability of coal with as received (AR) moisture and after air drying (AD), Method #2

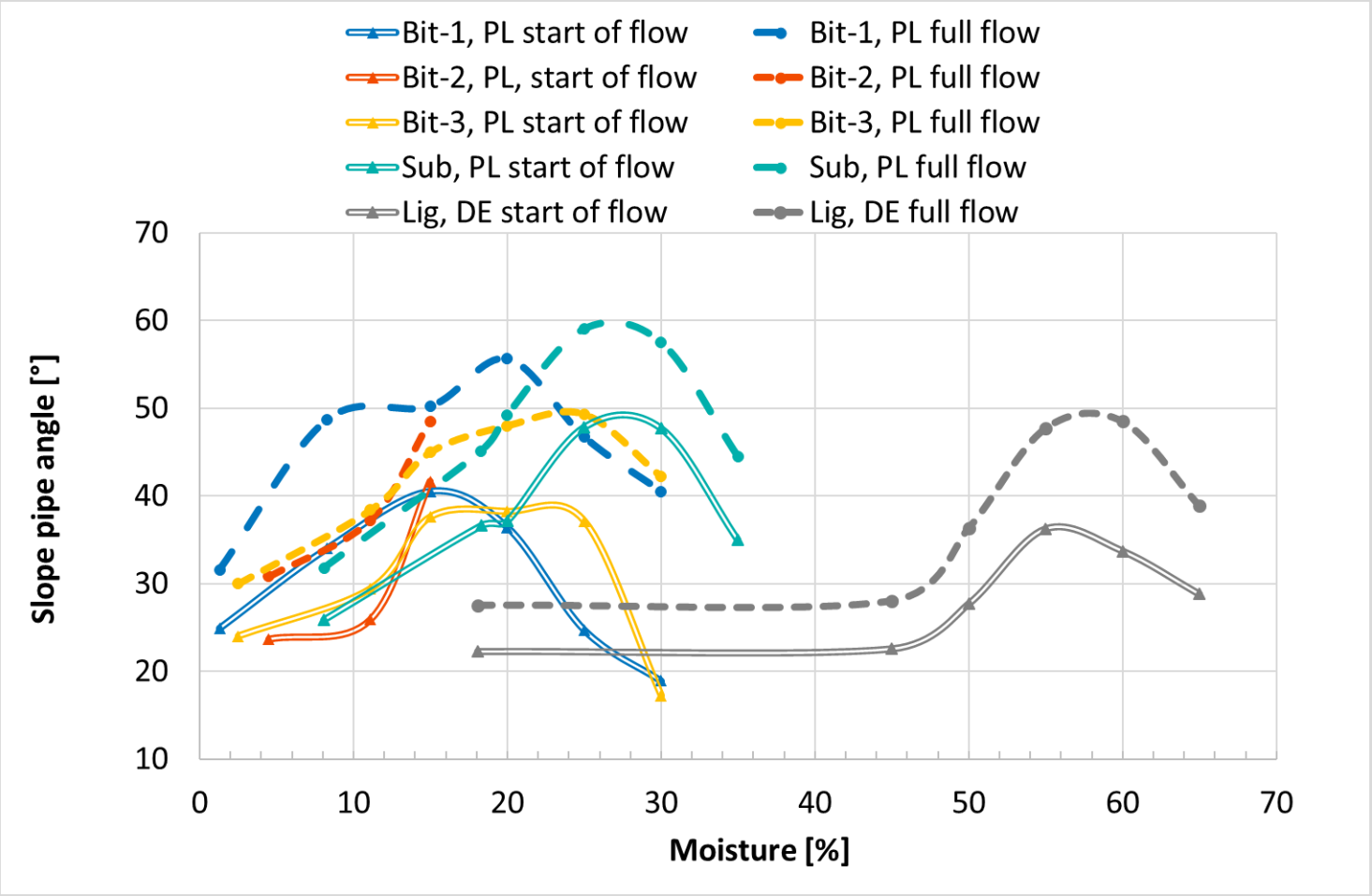




- Total moisture in analyzed coals (slide 7) is higher compared to coals used in experiments, with exception of Bit-1. Highest loss of moisture was in Lig, DE
- Good flowability was measured for all AR and AD samples, regardless of different moisture contents
- Flowability worsens with increase of moisture above AR

Experimental study

Method #1 – effect of moisture on start and full flow

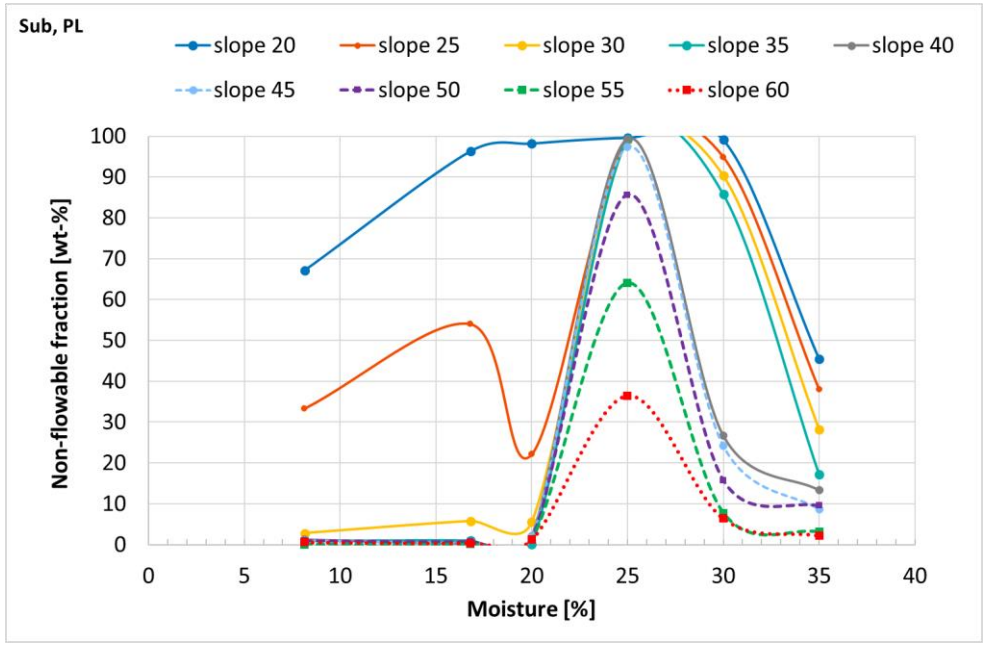


In this study threshold moisture content was around 15-27%, for Sub and Bit coals, ~55% for Lig

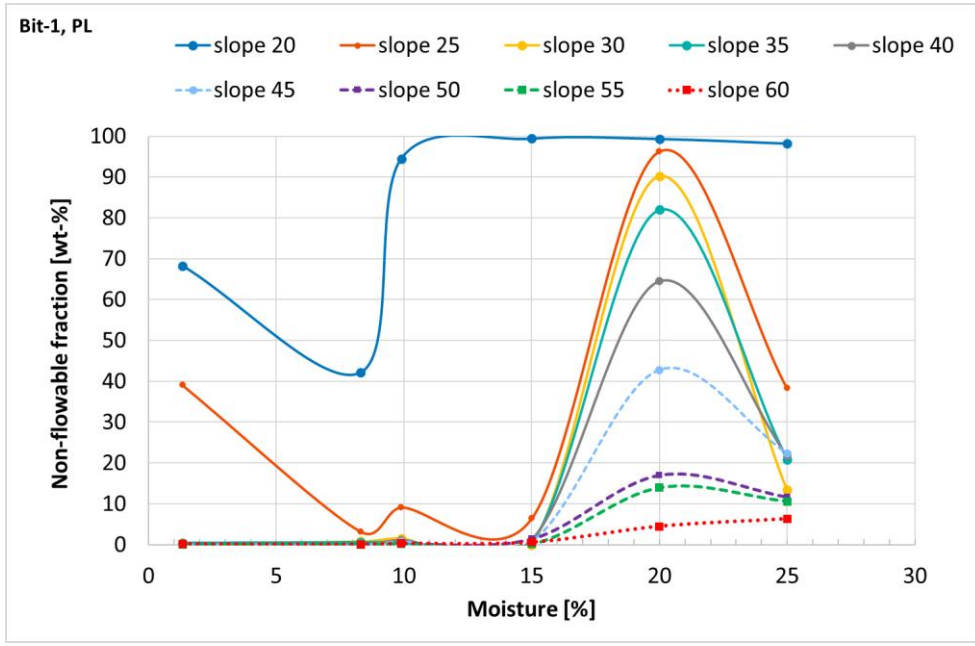
- Coal specific property

Experimental study

Method #2 – share of accumulated fuel fraction @slope angle



	All		<1 mm		>1 mm	
	Free M	Total	Free M	Total	Free M	Total
Sub, PL	10.8	18.3	12.8	19.6	9.8	16.9



	All		<1 mm		>1 mm	
	Free M	Total	Free M	Total	Free M	Total
Bit-1, PL	5.8	8.3	7.8	12.1	5.3	8

- Effect of moisture on coal flowability can be described with bell-shaped curve, i.e., flowability is improved at moisture levels beyond critical moisture content
- The critical moisture content is coal specific, however, does not seem to be connected to free moisture (ISO 589)
- Improved flowability with increase in slope

Take away

- Terminology used for moisture differs among standards, therefore, it is advisable to specify the standard when referring to moisture types
- Experimental equipment designed at SFW proves to be valuable research tool to assess flowability properties of coals
  - Coal flowability worsens when moisture exceeds total, “as received” value of that coal
  - Effect of moisture on coal flowability can be described with bell-shaped curve, i.e. flowability is improved at moisture levels beyond critical moisture content
  - Critical moisture content, i.e. moisture content for which coal shows worse flowability, seems to be coal specific but doesn’t seem to be a function of air-dry loss, or free moisture as defined by ISO standards
- Possible continuation of research at SFW:
  - Quantifying the effect PSD and temperature on flowability
  - Model development for prediction of coal flowability based on coal properties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