Rheological, viscoelastic and plastic properties of faecal sludge from VIP latrines

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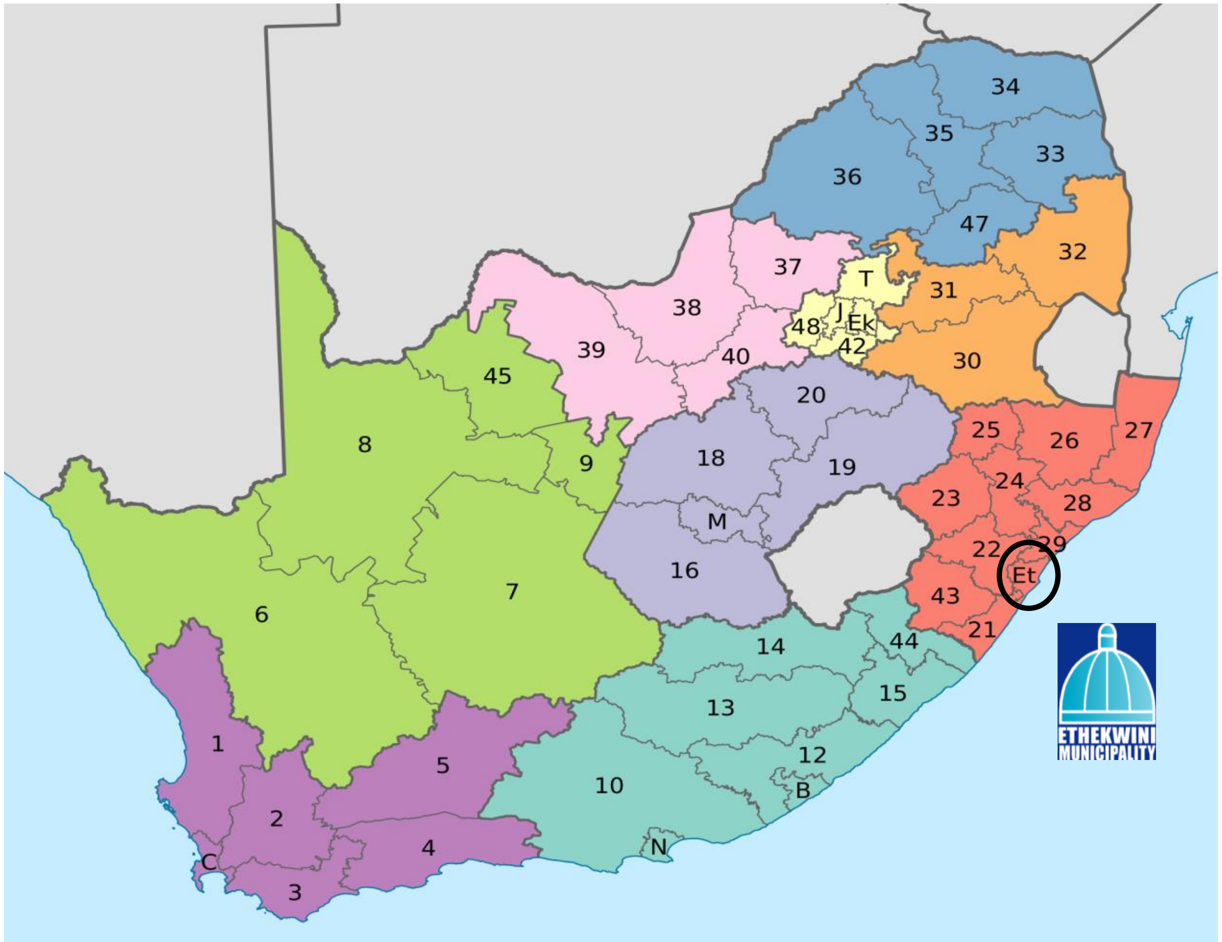
Motivation of the study

- VIP latrines widespread worldwide, particularly in the African context
- Faecal sludge an hazardous material
- Lack of data in literature about mechanical properties of faecal sludge
- Required for the design of pit emptying, mechanical handling and process equipment

Location of the study



30,000 VIP latrines

Methodology

Sampling

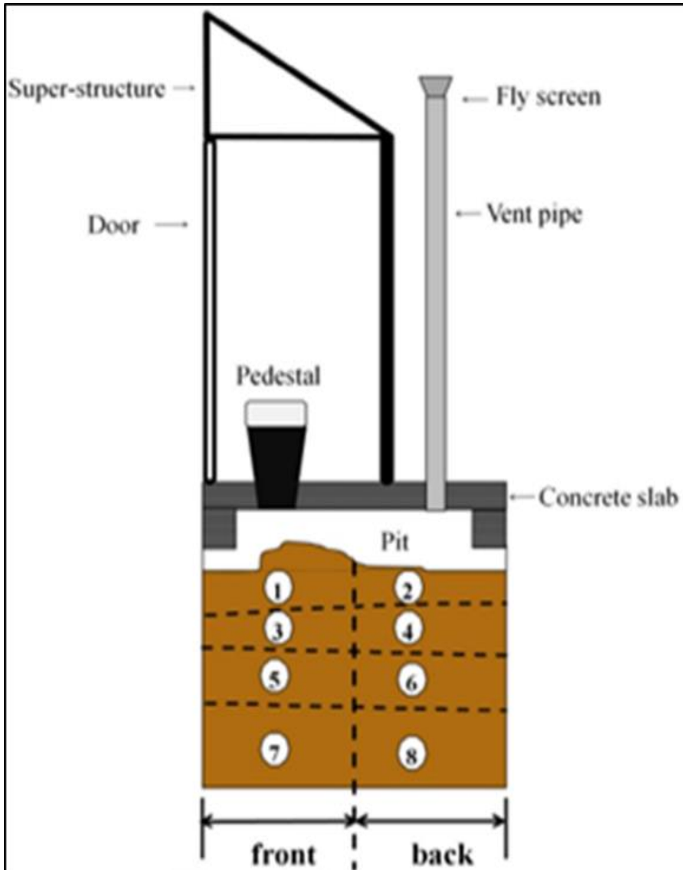


Diagram of a VIP latrine showing the layers from which the samples were selected in the front and back sections

Rheometer:
- Static tests (flow)
- Dynamic tests (viscoelasticity)

Cone penetrometer:
- Liquid limit
- Plastic limit

Moisture and ash content analysis

Methodology

Alteration of moisture content

- Addition of water to increase moisture content
- Mixing with dried sludge to lower moisture content

Rheometer:

- Static tests (flow)
- Dynamic tests (viscoelasticity)

Modelling

Power Law

$$\tau = K \cdot \dot{\gamma}^n \quad \begin{cases} K = a \cdot MC^b \\ n = c \cdot MC^d \end{cases}$$

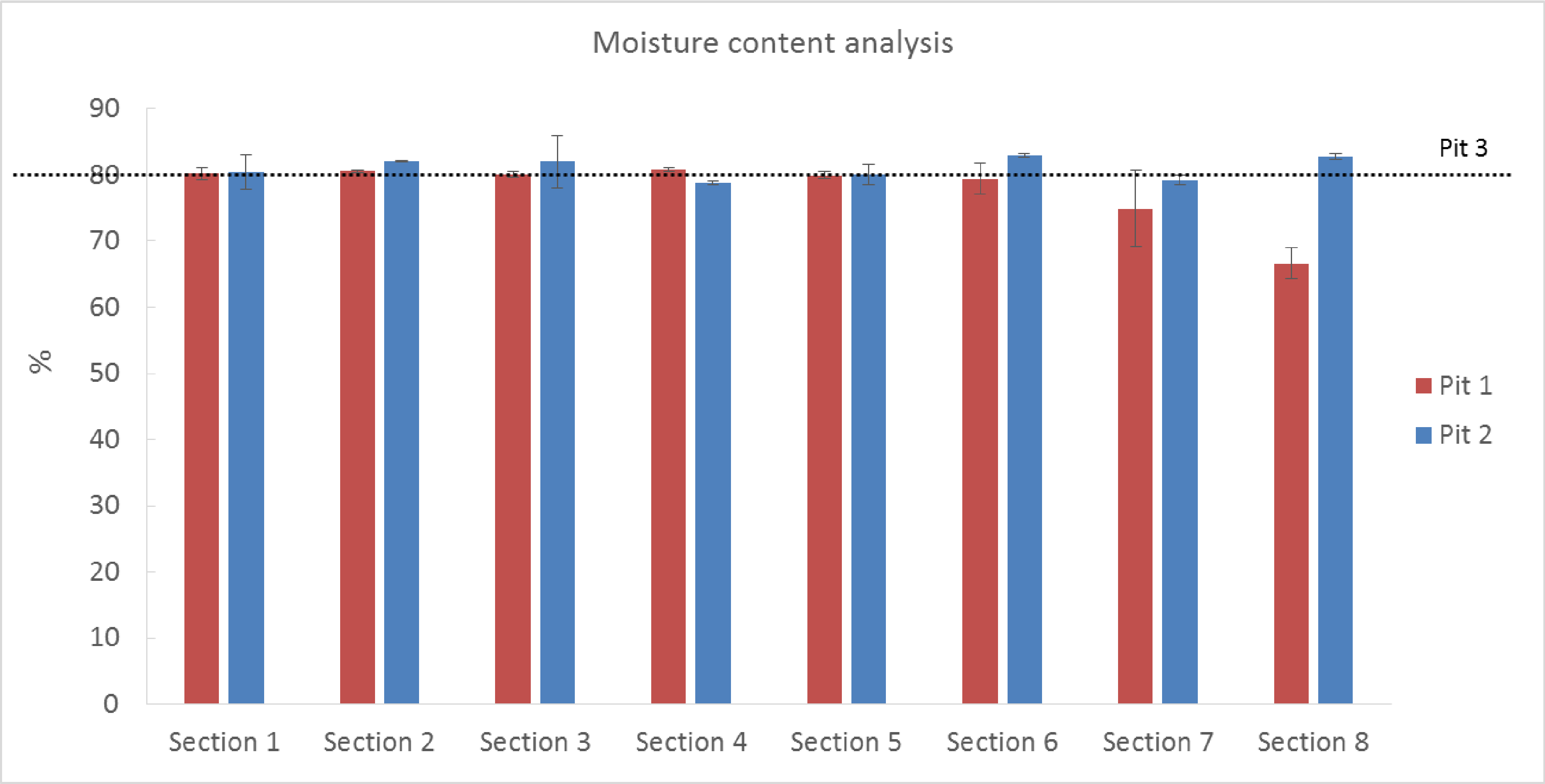
τ: shear stress [Pa]
$\dot{\gamma}$: shear rate [s^{-1}]
n : flow behaviour index [-]
K : consistency coefficient

Application for pit emptying

$$\Delta P = \frac{4 \cdot \rho \cdot f \cdot L \cdot V^2}{2 \cdot D} \quad \begin{cases} f = \dfrac{16}{Re'} \\ Re' = \dfrac{VD\rho}{K}\left(\dfrac{4n}{1+3n}\right)^n \left(\dfrac{D}{8V}\right)^{n-1} \\ V = \dfrac{Q}{\pi \cdot \left(\dfrac{D}{2}\right)^2} \end{cases}$$

V: average velocity [m·s^{-1}]
D : pipe diameter [m]
L : pipe length [m]
ρ_m: sludge density [kg·m^{-3}]
f: friction factor [-]
Re': power law modified Reynolds number [-]
ΔP: total frictional pressure drop in the pipe [Pa]

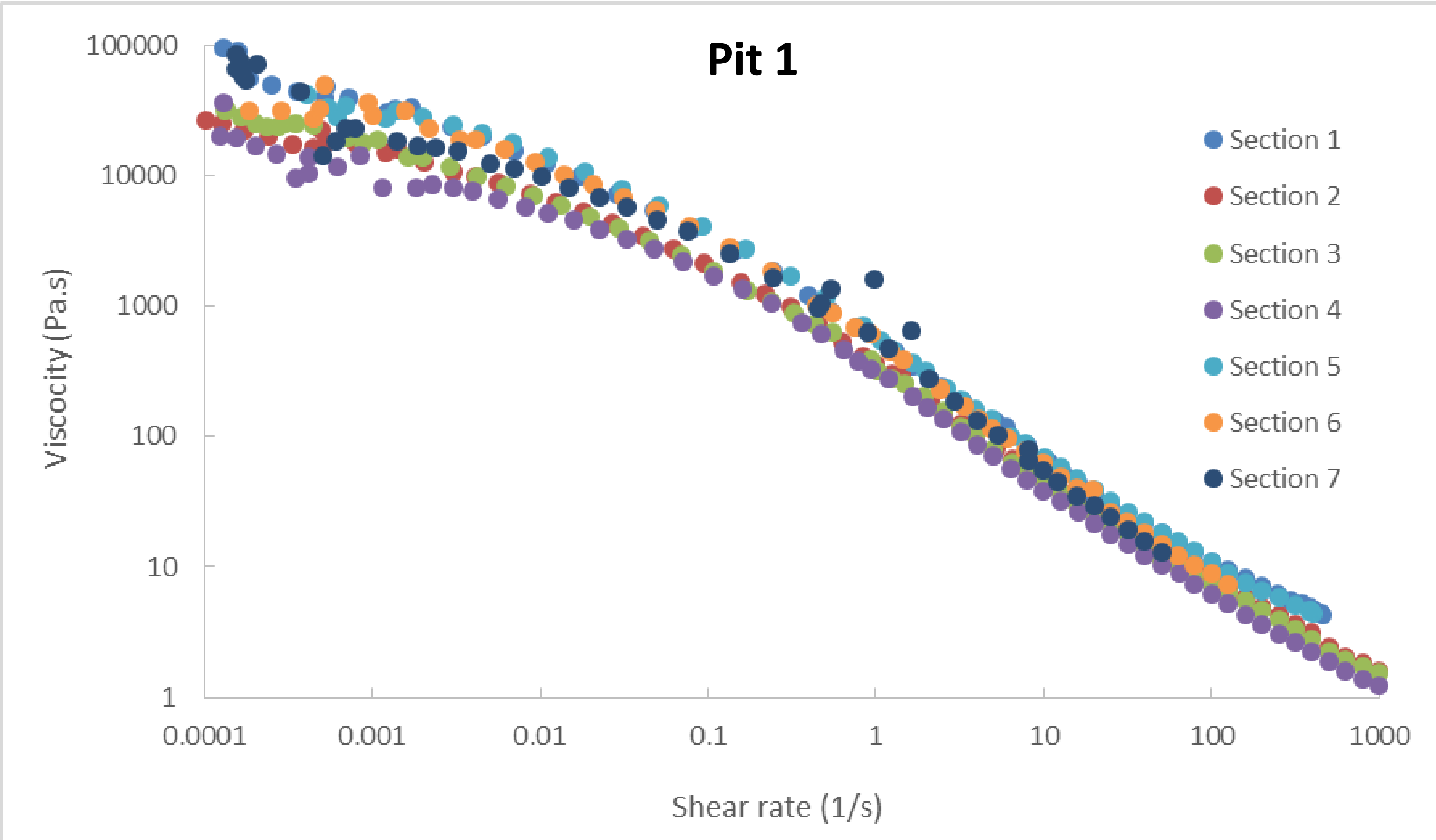
Composition sludge



~ 80% moisture, except for section 8, pit 1 (~ 65%)

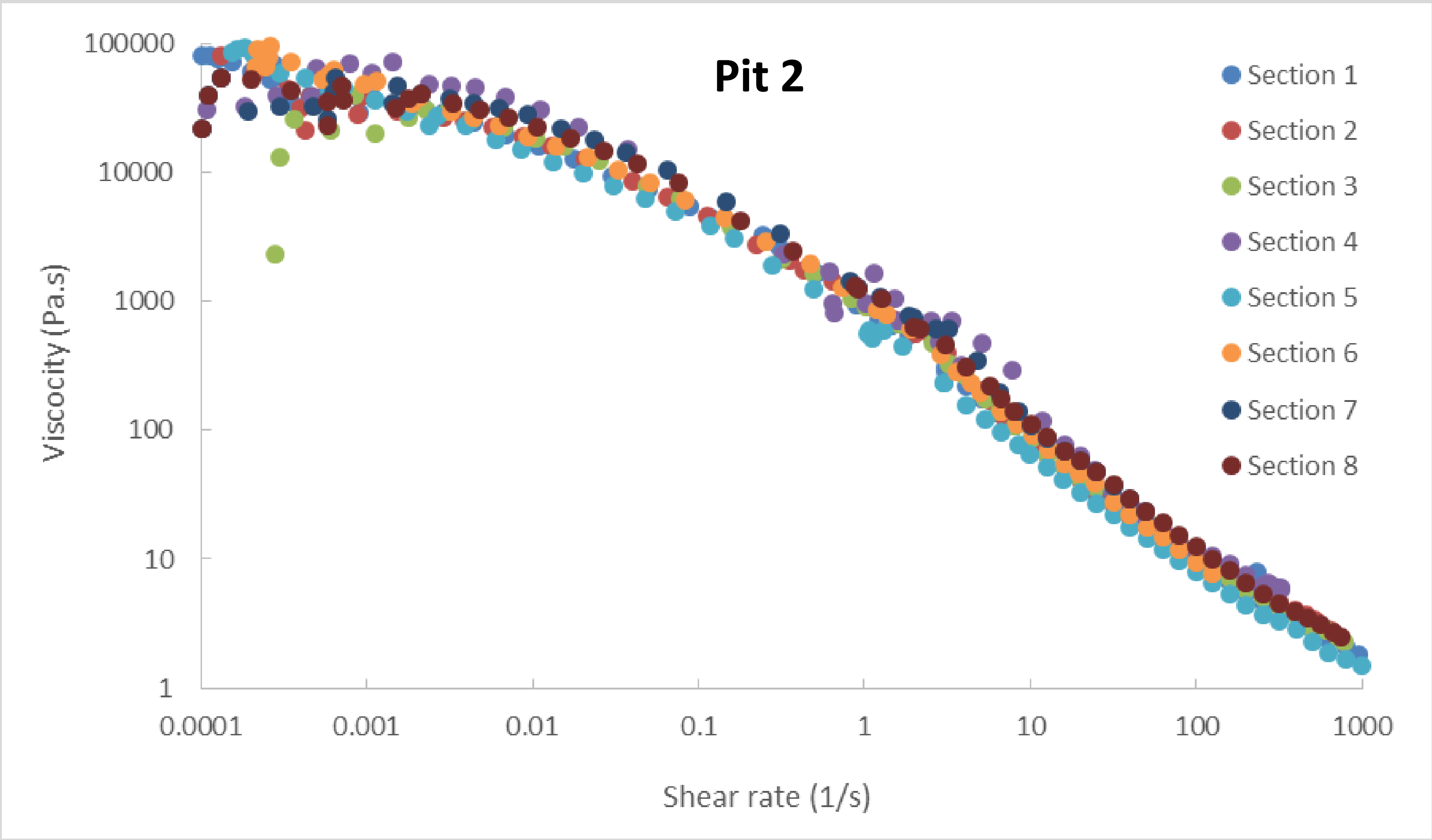
~ 35 % ash

Viscosity - comparison between pit sections



Section 8: not possible to perform analysis (no flow possible)

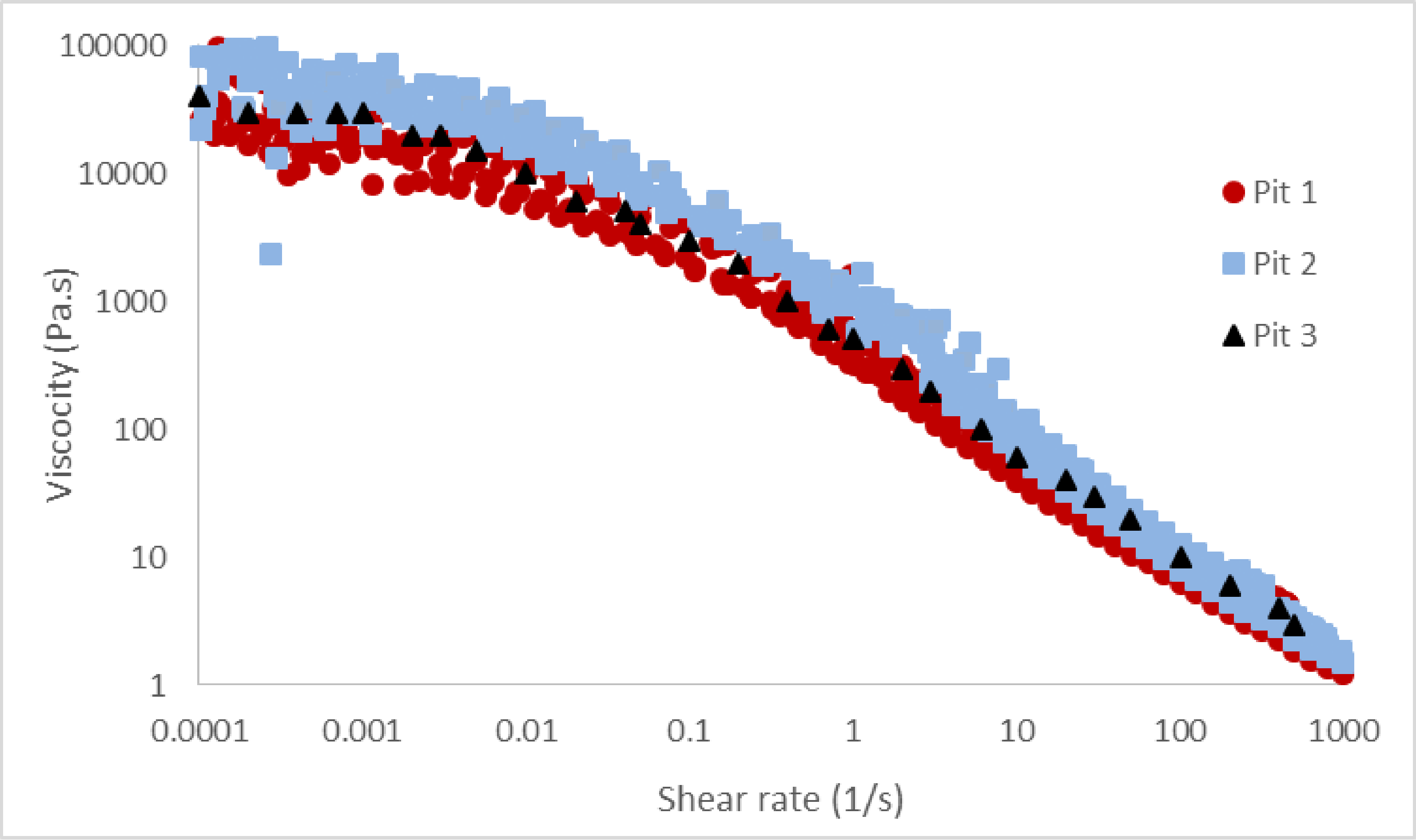
Viscosity - comparison between pit sections



SHEAR THINNING BEHAVIOUR

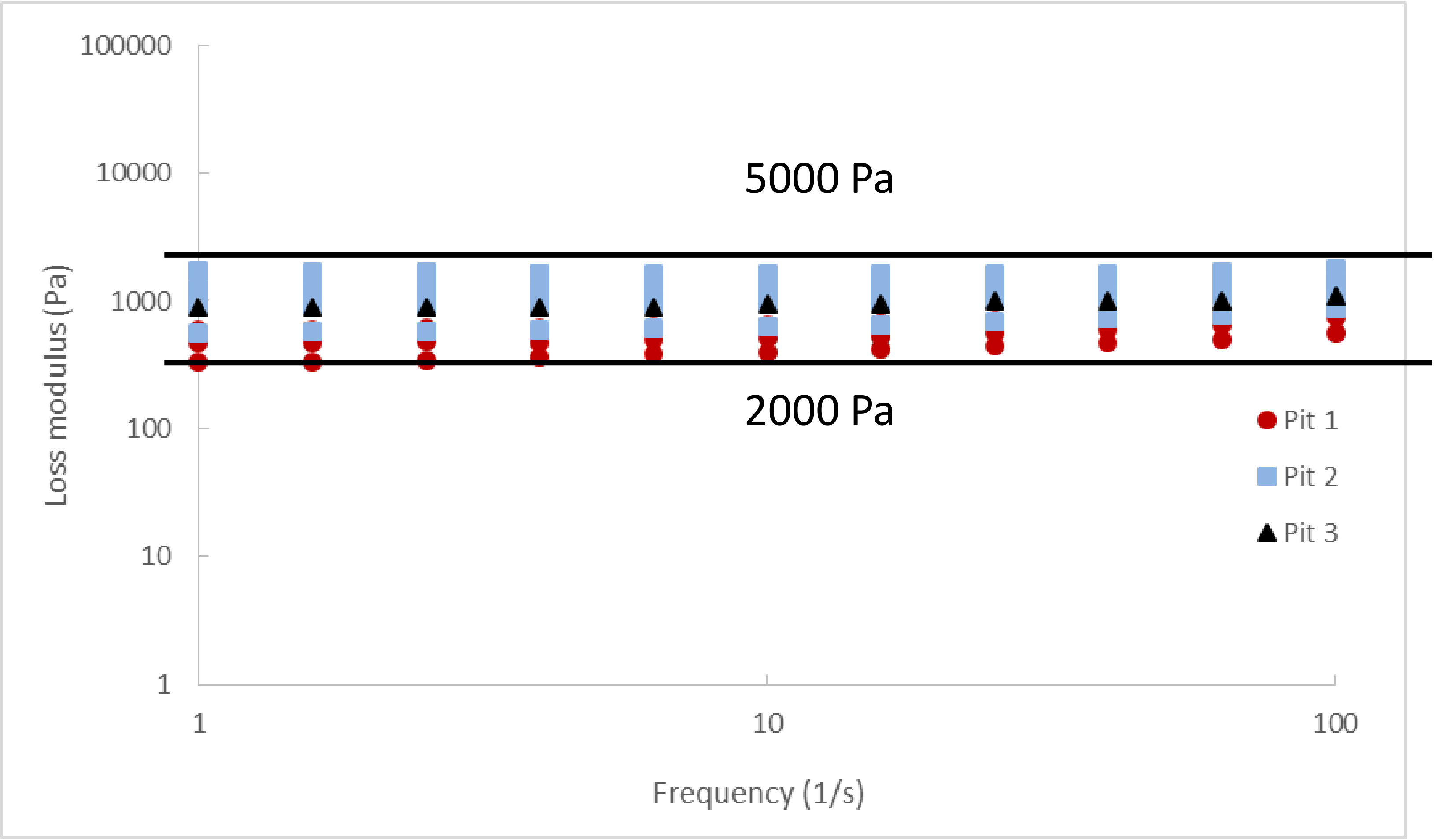
NO EFFECT OF PIT SECTION

Viscosity - comparison between pits

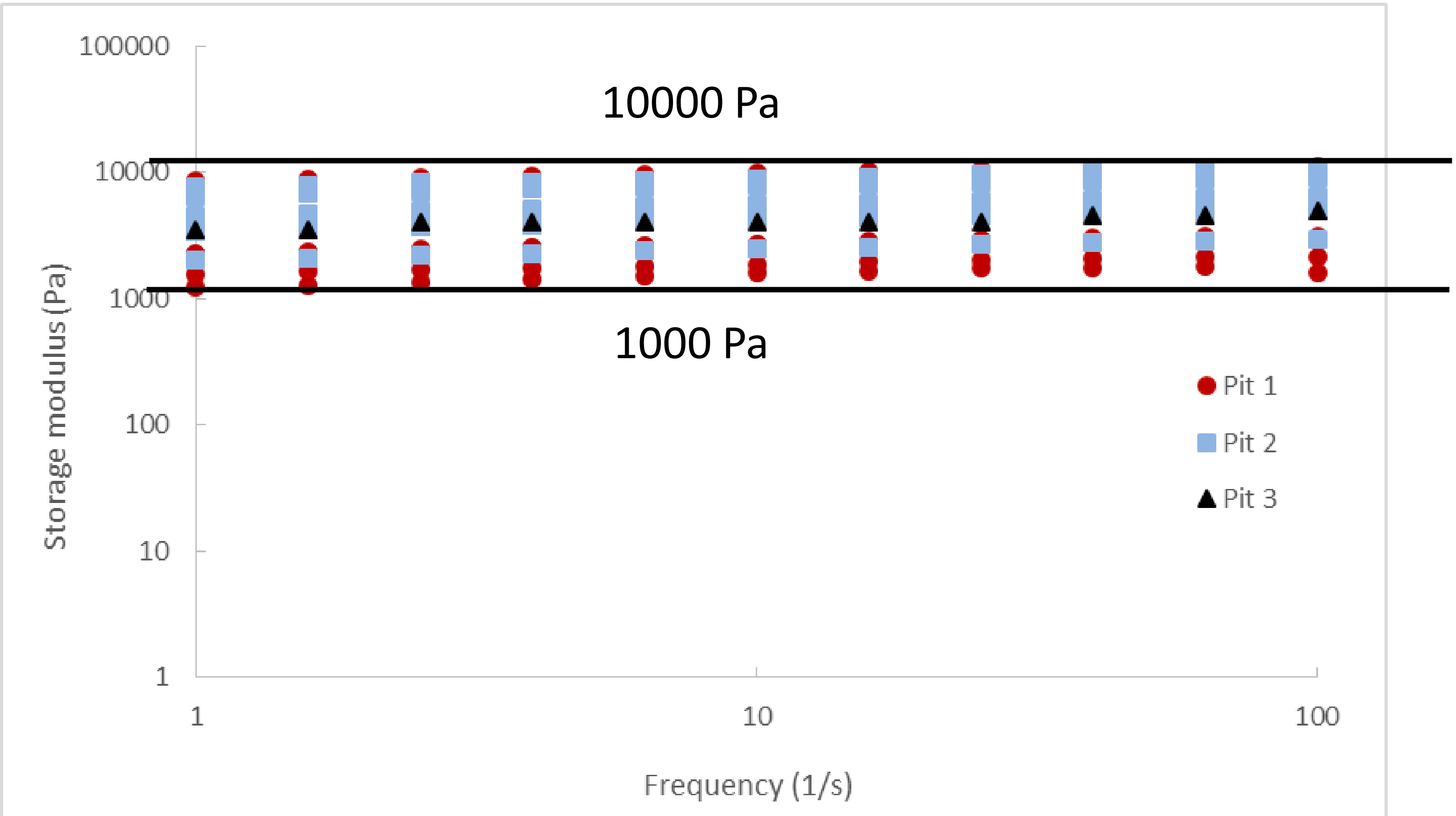


SAME BEHAVIOUR FOR DIFFERENT PITS

Viscoelastic properties



Viscoelastic properties



Viscoelastic properties

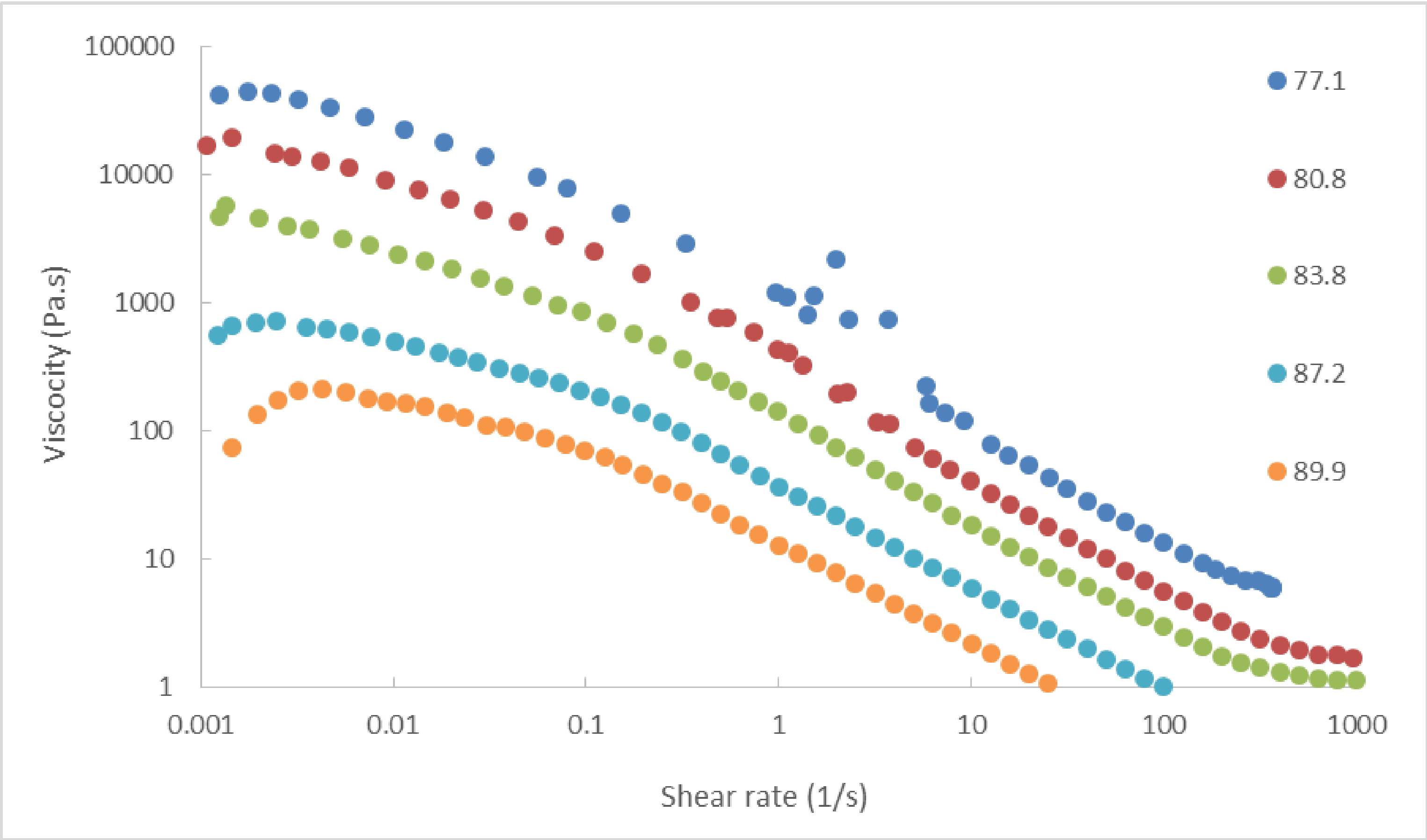
Damping factor = Loss modulus / Storage modulus < 1

ELASTICITY > VISCOCITY

YIELD STRESS FOR FLOW

(~1 – 20 Pa)

Effect of moisture content of sludge



DECREASE OF MOISTURE CONTENT

→ DECREASE OF VISCOCITY

Effect of moisture content of sludge

Damping factor for different moisture contents < 1

DECREASE OF MOISTURE CONTENT

→ INCREASE DAMPING FACTOR

→ DECREASE OF YIELD STRESS (< 1 Pa)

Modelling

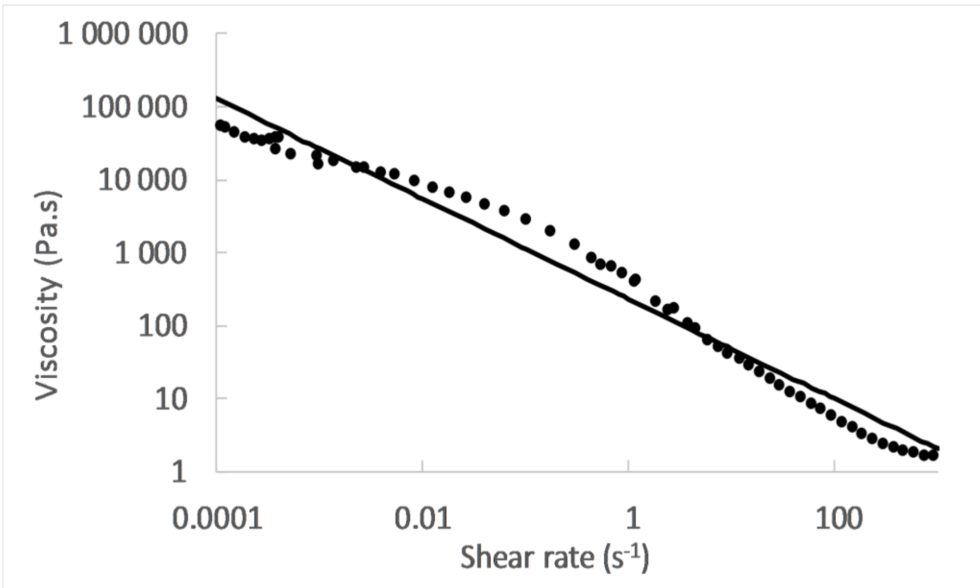
Power Law

$$\tau = K \cdot \dot{\gamma}^n \quad \begin{cases} K = 1.9 \times 10^{51} \cdot MC^{-25.7} \\ n = 3.2 \times 10^{-4} \cdot MC^{1.6} \end{cases}$$

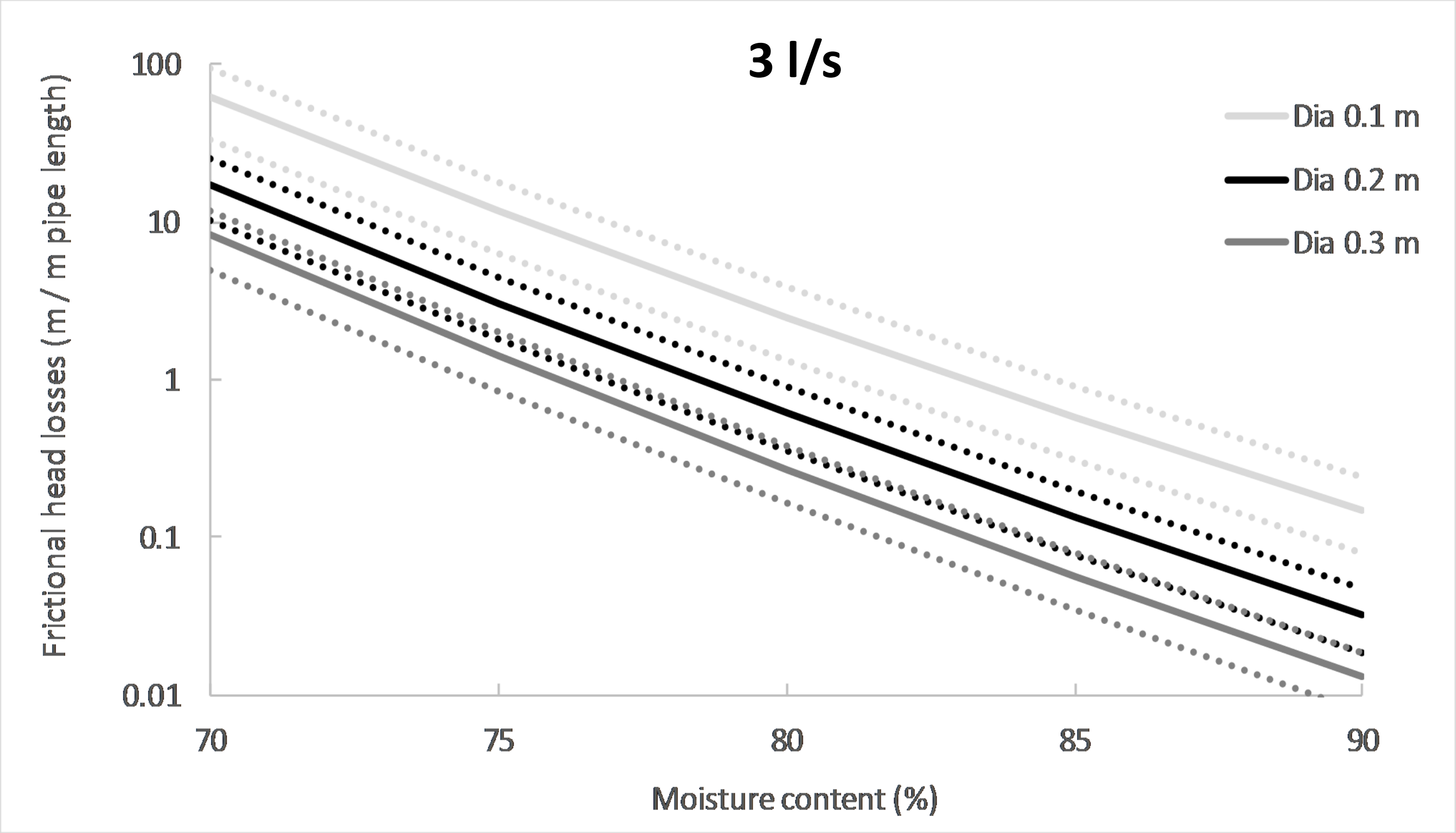
Different from fresh faeces (Wolley et al. (2014))

Average deviation of 13 and 5% for *K* and *n*, respectively

Maximum deviation of 37 and 9% for *K* and *n*, respectively



Pumping requirements



INCREASE OF PUMPABILITY

→ **INCREASE OF MOISTURE CONTENT**

→ **INCREASE OF PIPE DIAMETER**

Pumping requirements

Omni-Ingestor criteria:

- Pit emptying rate = 3 l/s
- Pipe horizontal length = 100 m ; vertical length = 20 m

	Pipe diameter (m)	Moisture %			
		75	80	85	90
Hydraulic head (m)	0.2	924-2537	180 -479	52-115	27-42
	0.3	298-714	65 -133	28-41	22-24
Pressure (bar)	0.2	125-344	24-65	7.1-16	3.7-5.7
	0.3	40-97	8.8-18	3.8-6.0	2.9-3.3
Power (kW)	0.2	38-104	7.4-20	2.1-4.7	1.1-1.7
	0.3	12-29	2.7-5.5	1.2-1.7	0.9-1.0

Plasticity and extrusion

Moisture content

80% — Raw sludge → No pelletization possible

77% — Sludge + Sawdust → Pelletization possible

75% — Liquid limit

70% — Plastic limit

PLASTICITY SUITABLE FOR EXTRUSION

65% — Liquid limit

60% — Plastic limit

Sludge LaDePa (pre-dried) → Pelletization possible

Conclusion about VIP faecal sludge

- ❑ Shear thinning fluid
- ❑ Elastic behaviour at rest → yield stress
- ❑ Similar rheological behaviour within the pit and among different latrines
- ❑ Low plasticity of sludge, so need to add a plasticiser (example: sawdust) or dewatering for extrusion
- ❑ Addition of water leading to the reduction of viscosity and yield stress → significant increase of pumpability

  However: Addition of water not suitable depending on the upstream process (extrusion, drying)

Let's evolve to a safer pit emptying!

Thanks a lot!

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