Facts, Figures and Fallacies about Faeces, Farts & Faecal Sludge

Without data it is just an opinion…

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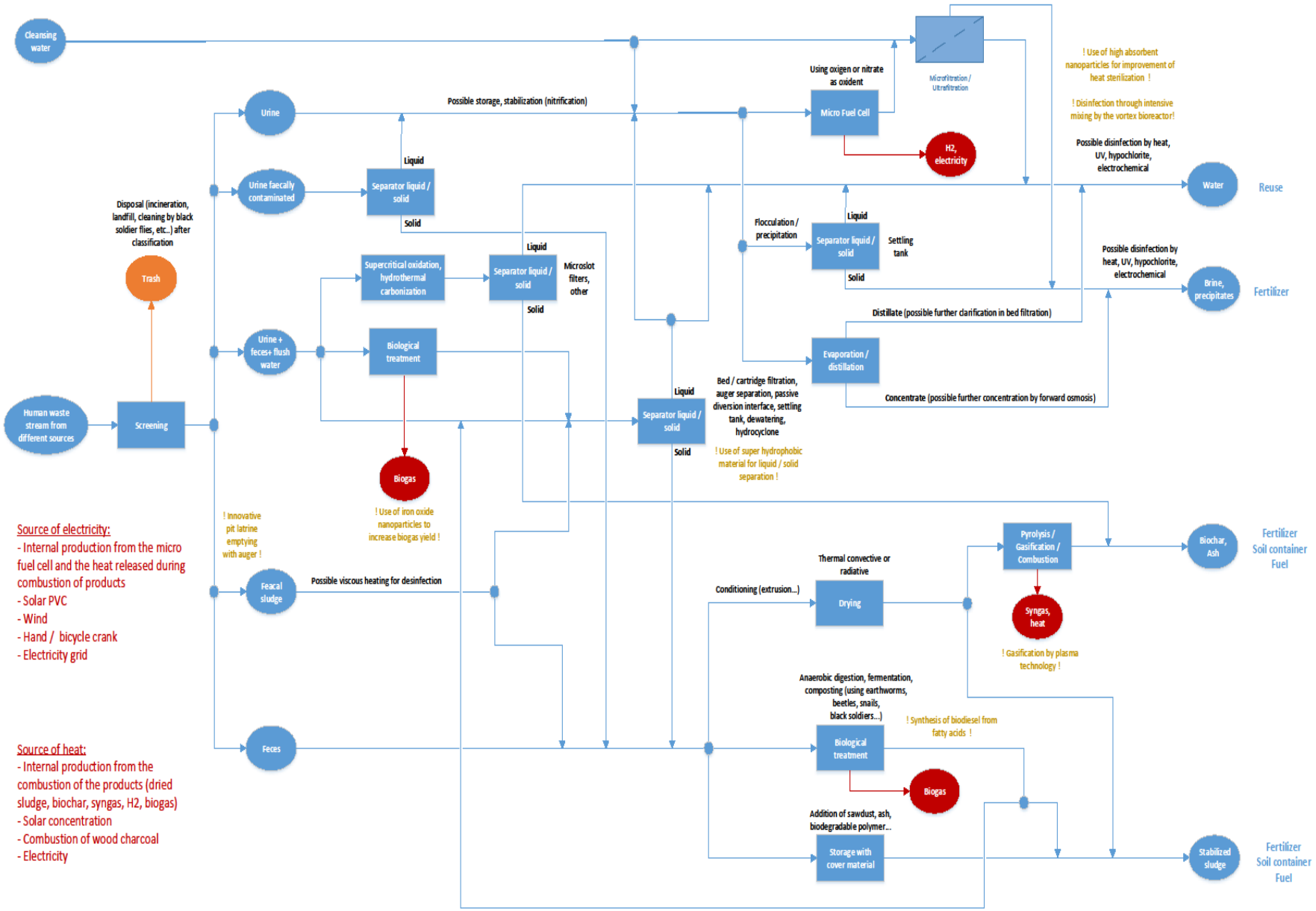
WATER RESEARCH COMMISSION


Cleansing water
Urine
Urine faecally contaminated
Urine + feces+ flush water
Feacal sludge
Feces
Human waste stream from different sources
Screening
Trash
Disposal (incineration, landfill, cleaning by black soldier flies, etc..) after classification
Separator liquid / solid
Liquid
Solid
Possible storage, stabilization (nitrification)
Supercritical oxidation, hydrothermal carbonization
Microslot filters, other
Biological treatment
Biogas
! Use of iron oxide nanoparticles to increase biogas yield !
! Innovative pit latrine emptying with auger !
Possible viscous heating for desinfection
Microfiltration / Ultrafiltration
! Use of high absorbent nanoparticles for improvement of heat sterilization !
! Disinfection through intensive mixing by the vortex bioreactor!
Using oxigen or nitrate as oxident
Micro Fuel Cell
H2, electricity
Possible disinfection by heat, UV, hypochlorite, electrochemical
Water
Reuse
Flocculation / precipitation
Settling tank
Possible disinfection by heat, UV, hypochlorite, electrochemical
Brine, precipitates
Fertilizer
Distillate (possible further clarification in bed filtration)
Evaporation / distillation
Concentrate (possible further concentration by forward osmosis)
Bed / cartridge filtration, auger separation, passive diversion interface, settling tank, dewatering, hydrocyclone
! Use of super hydrophobic material for liquid / solid separation !
Conditioning (extrusion...)
Thermal convective or radiative
Drying
Pyrolysis / Gasification / Combustion
Biochar, Ash
Fertilizer
Soil container
Fuel
Syngas, heat
! Gasification by plasma technology !
Anaerobic digestion, fermentation, composting (using earthworms, beetles, snails, black soldiers...)
Biological treatment
! Synthesis of biodiesel from fatty acids !
Biogas
Addition of sawdust, ash, biodegradable polymer...
Storage with cover material
Stabilized sludge
Fertilizer
Soil container
Fuel
Source of electricity:
- Internal production from the micro fuel cell and the heat released during combustion of products
- Solar PVC
- Wind
- Hand / bicycle crank
- Electricity grid
Source of heat:
- Internal production from the combustion of the products (dried sludge, biochar, syngas, H2, biogas)
- Solar concentration
- Combustion of wood charcoal
- Electricity

Excreta facts and figures

	Units	Urine	Faeces	Toilet paper	Black water (urine + faeces)
wet mass	kg/person.y	550	51	8.9	**610**
dry mass	kg/person.y	21	11	8.5	**40**
nitrogen	kg/person.y	4	0.55		**4.5**
phosphorus	kg/person.y	0.36	0.18		**0.55**

Vinnerås et al. 2006

most pathogens are in the faeces
most nutrients are in the urine

Excreta plus flush water

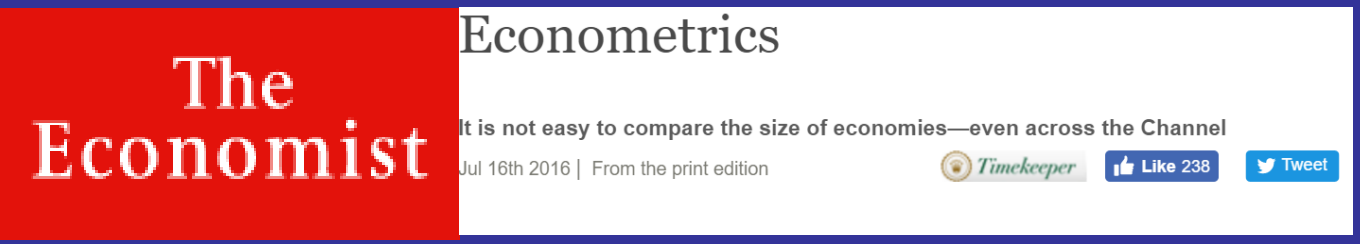
	Units	Black water (urine + faeces)	Black water + Flush water
wet mass	kg/person.y	**610** →	**18,000**
dry mass	kg/person.y	40	**40**
nitrogen	kg/person.y	4.5	**4.5**
phosphorus	kg/person.y	0.5	**0.5**

all pathogens are in the water!

What is the value of faeces?

Even economists are interested in faecal sludge!!

…added over $180m to India's GDP, assuming an "evacuation rate" of 0.3kg a day for goats and rather more for sheep …



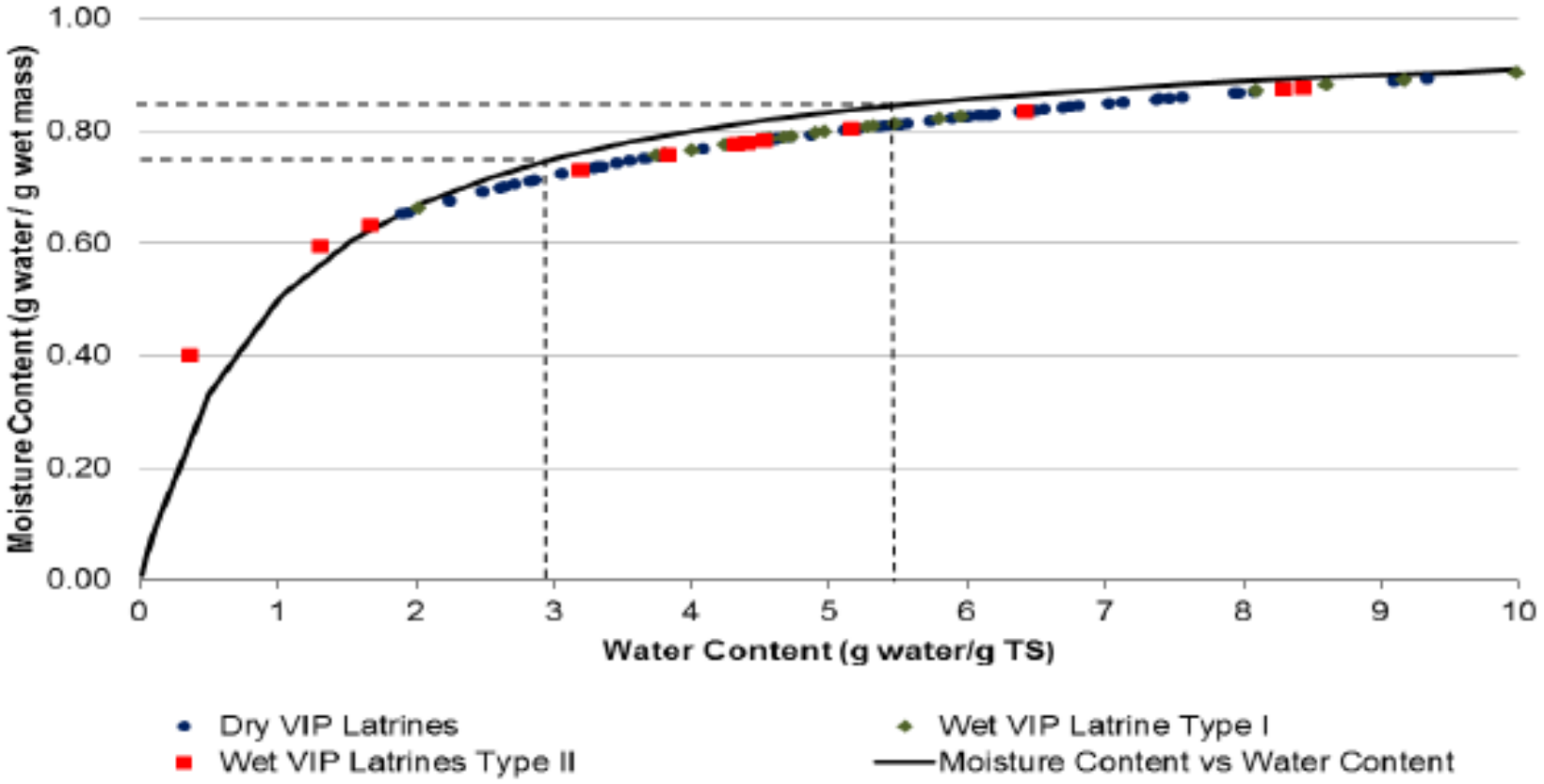
Bristol Stool Chart

Bristol Stool Chart - Developed at University of Bristol

Type.1		Separate hard lumps, like nuts (hard to pass)
Type.2		Sausage-shaped but lumpy
Type.3		Like a sausage with cracks on its surface
Type.4		Like a sausage, smooth and soft
Type.5		Soft blobs, clear cut edges (passed easily)
Type.6		Fluffy pieces, ragged edges, mushy stool
Type.7		Watery, no solid pieces. Entirely liquid

Lewis SJ, Heaton KW (1997). "Stool form scale as a useful guide to intestinal transit time". *Scand. J. Gastroenterol.* **32** (9): 920–4

Moisture content and solid content



Zuma, L 2015. MScEng dissertation, University of KwaZulu-Natal (submitted)

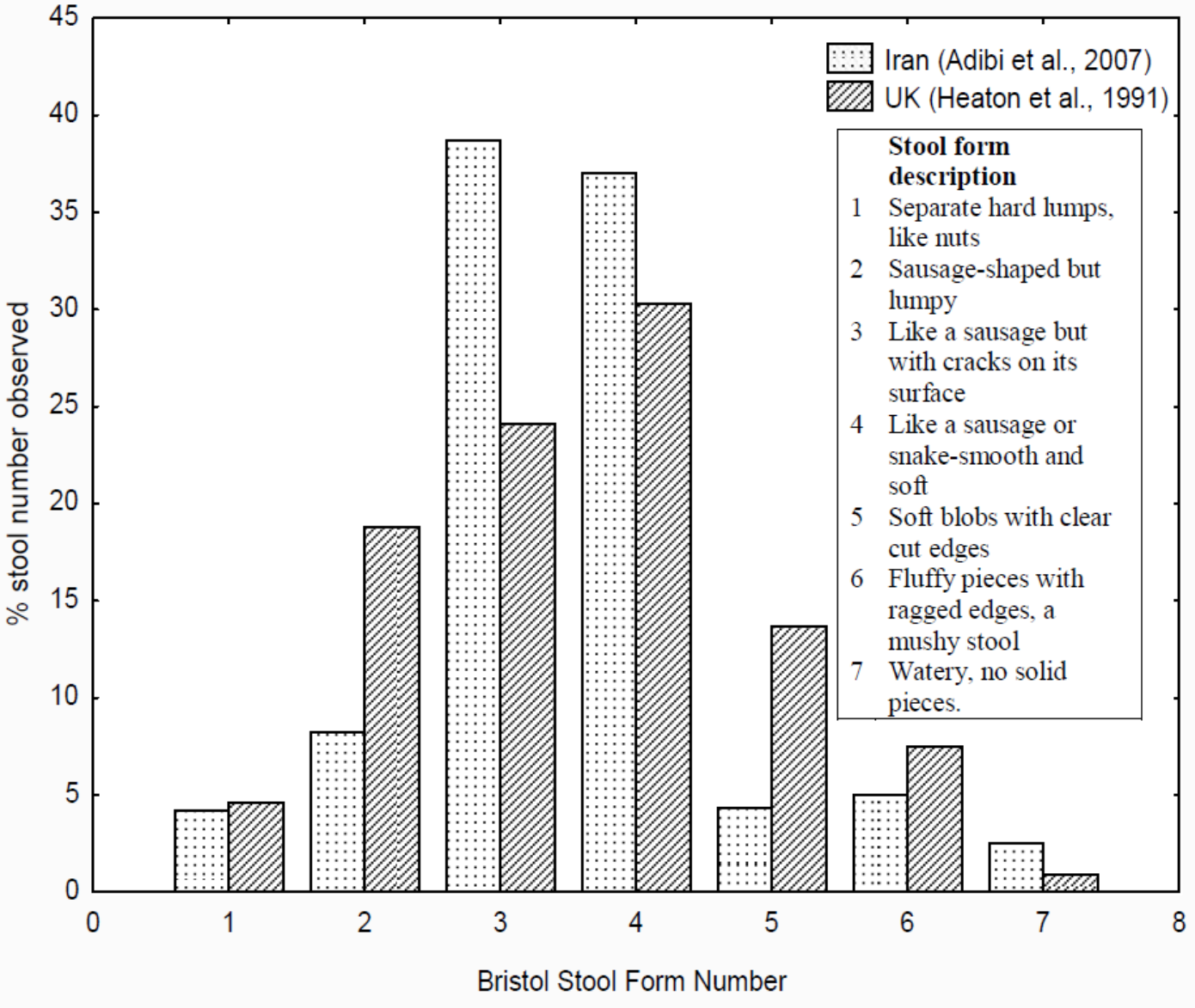
Excreta Characteristics

Key design criteria	Median value
Faeces	
Faecal wet weight (g/cap/day)	128
Faecal dry weight (g/cap/day)	29
Stool Frequency (motions/24 hours)	1.1
Total Solids (%)	25
VS (% of TS)	89
COD (g/cap/day)	71
Nitrogen (g/cap/day)	1.8
Protein (g/cap/day)	6.3
Lipids (g/cap/day)	4.1
Carbohydrate (g/cap/day)	9
Fibre (g/cap/day)	6
Calorific value (kcal/cap/day)	132
pH	6.6
Urine	
Urine wet weight (L/cap/day)	1.4
Urine dry weight (g/cap/day)	59
Urination frequency (urinations/24 hours)	6
Nitrogen (g/cap/day)	11
Calorific value (kcal/cap/day)	1701
pH	6.2

C. Rose, A. Parker, B. Jefferson & E. Cartmell (2015): The characterisation of faeces and urine; a review of the literature to inform advanced treatment technology, Critical Reviews in Environmental Science and Technology,

DOI: 10.1080/10643389.2014.1000761
http://dx.doi.org/10.1080/10643389.2014.1000761

Stool Consistency Distribution



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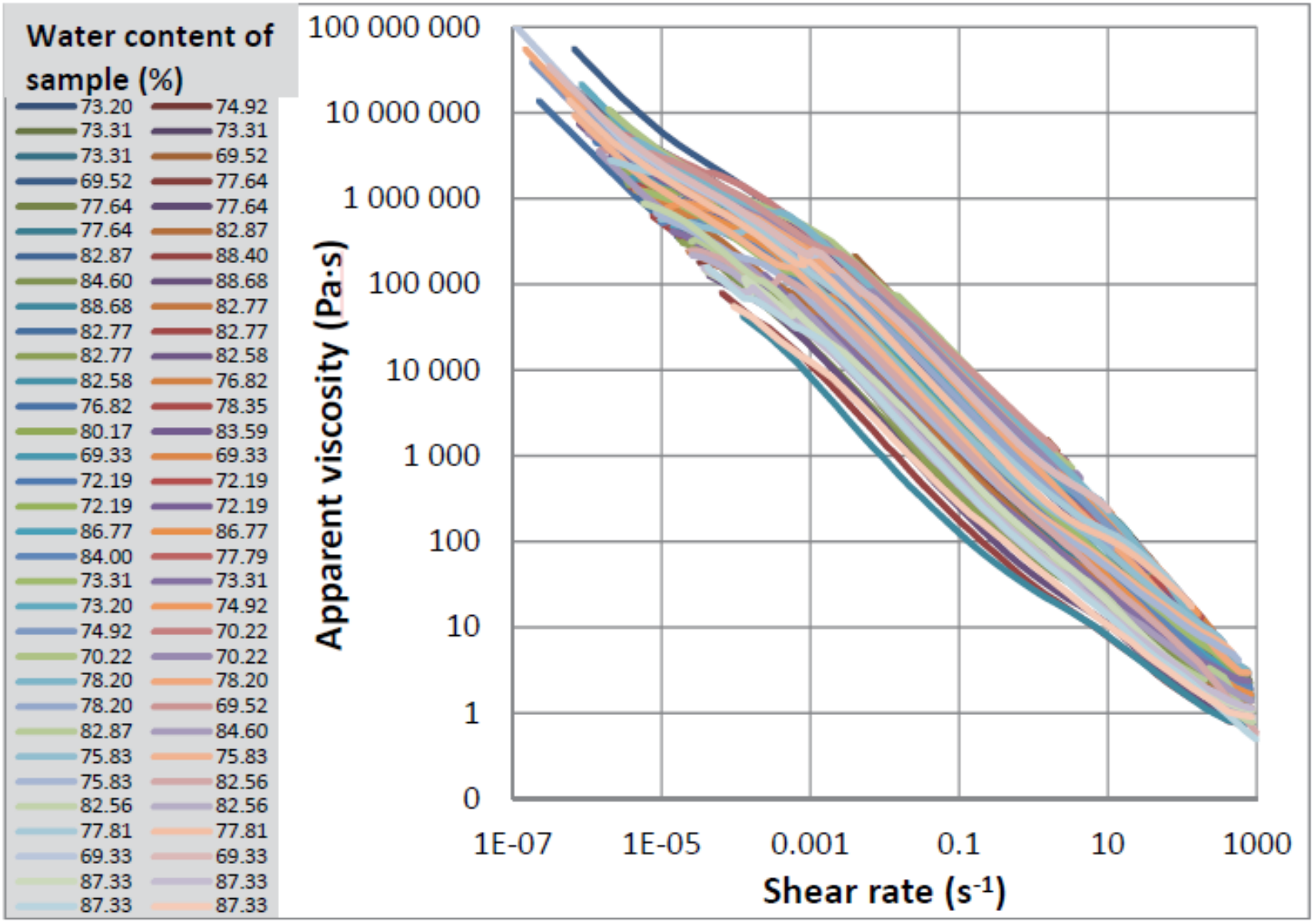
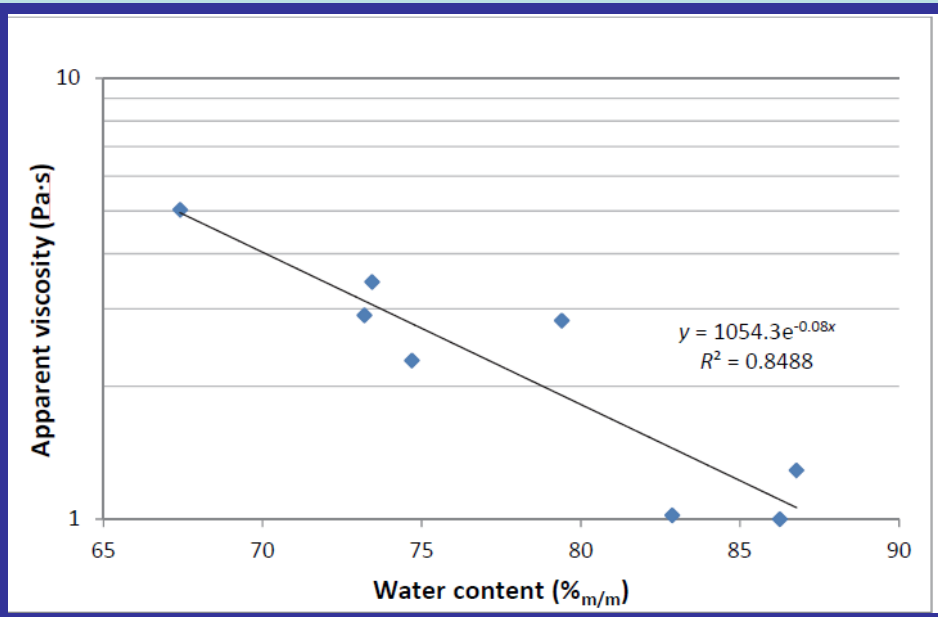
Viscosity fresh faeces

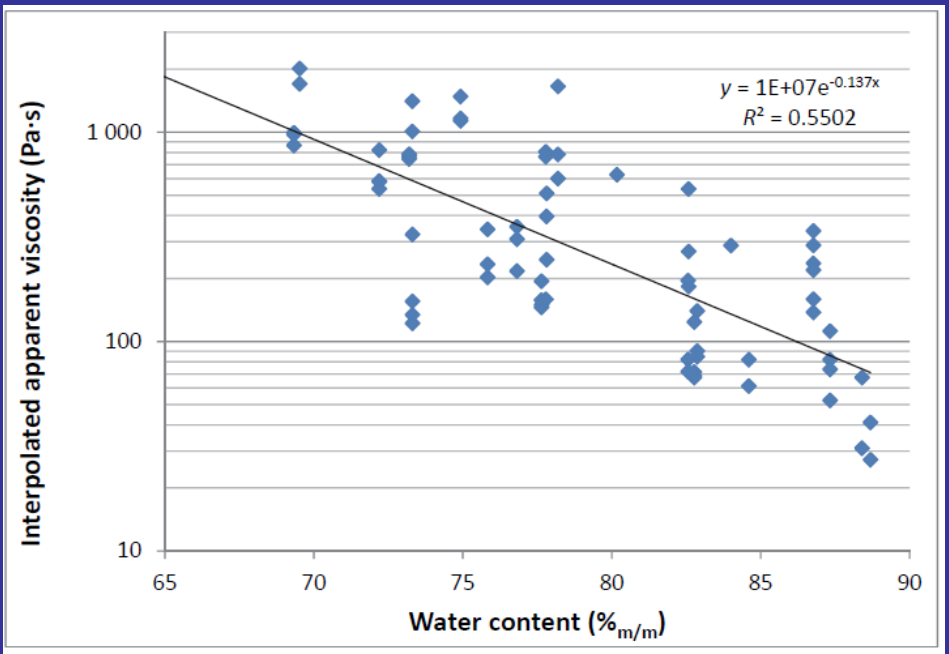


Woolley, SM, Cottingham, RS, Pocock, J and Buckley, CA (2014), **Shear rheological properties of fresh human faeces with different moisture content.** Water SA Vol. 40 pp 273 – 276.

Changes in viscosity of fresh faeces

Variation in apparent viscosity of fresh human faeces of sample on a dry basis (applied shear rate of 1 s_{-1} at 25°C)





Apparent viscosity of fresh human faeces after 1 h of shearing at 100 s1 for various moisture contents (at 25°C)

Woolley, SM, Cottingham, RS, Pocock, J and Buckley, CA (2014), **Shear rheological properties of fresh human faeces with different moisture content.** Water SA Vol. 40 pp 273 – 276.

Malodour – fresh faeces and urine

	Compound	Concentration (ppm)	Percentage (%)[a)]
Fatty acids	Acetic acid	40.00–120.00	65.00
	Propionic acid	5.30–27.00	15.00
	Butyric acid	1.50–9.20	6.50
	i-Valeric acid	0.53–2.60	2.30
	n-Valeric acid	0.41–1.60	1.40
S-containing compounds	Hydrogen sulfide	19.00–50.00	1.60
	Methyl mercaptane	0.70–1.10	0.62
N-containing compounds	Pyridine	0.03–0.23	0.14
	Pyrrole	0.01–0.02	0.01
	Indole	0.02–0.35	0.31
	Skatole	0.10–0.48	0.55
	Ammonia[b)]	18.00–34.00	6.50
	Trimethylamine[b)]	0.80–1.20	0.60

Sato, H, Hirose, T, Kimura, T, Moriyama, Y and Nakashimab, Y (2001). Analysis of Malodorous Volatile Substances of Human Waste: Feces and Urine. *Journal of Health Science,* **47**(5) pp483 - 490

Odour with diarrhea

Normal

Sample No.	Acetic acid	Propionic acid	Butyric acid	*iso*-Valeric acid	*n*-Valeric acid	Pyridine	Pyrrole (ppb)
1	< 1	< 1	0.24	0.03	0.01	8	2
2	< 1	2	0.02	0.01	0.01	6	3
3	< 1	< 1	0.08	0.01	0.01	8	2
4	10	1	0.20	0.03	0.01	5	1
5	5	5	0.11	0.05	0.01	9	1
6	< 1	11	0.12	0.04	0.01	8	3
7	4	< 1	0.15	0.10	0.05	10	1
8	7	7	0.30	0.01	0.01	1	1
9	3	< 1	0.35	0.02	0.04	5	1
10	< 1	< 1	0.02	0.01	0.01	2	2
Ave	3	3	0.16	0.03	0.02	6	2

With diarrhea

Sample No.	Acetic acid	Propionic acid	Butyric acid	*iso*-Valeric acid	*n*-Valeric acid	Pyridine	Pyrrole (ppm)
11	497	2.8	2.0	0.03	0.77	0.10	0.01
12	600	3.5	3.0	0.30	0.90	0.20	0.03
Ave	549	3.1	2.5	0.32	0.84	0.15	0.02

Sato, H, Morimatsu, Kimura, T, Moriyama, Y Yamashita, T and Nakashima, Y (2002). Analysis of Malodorous Volatile Substances of Human Feces. *Journal of Health Science,* **48**(2) pp179 - 185

Synthetic fresh and hydrolysed urine up to 10X concentration

Vapour Pressure

$$\log_{10} P = A - \frac{B}{T} + \frac{C}{T^2}$$

Synthetic fresh and hydrolysed urine up to 10X concentration

Osmotic Pressure

$$\pi = A + BX + CX^2$$

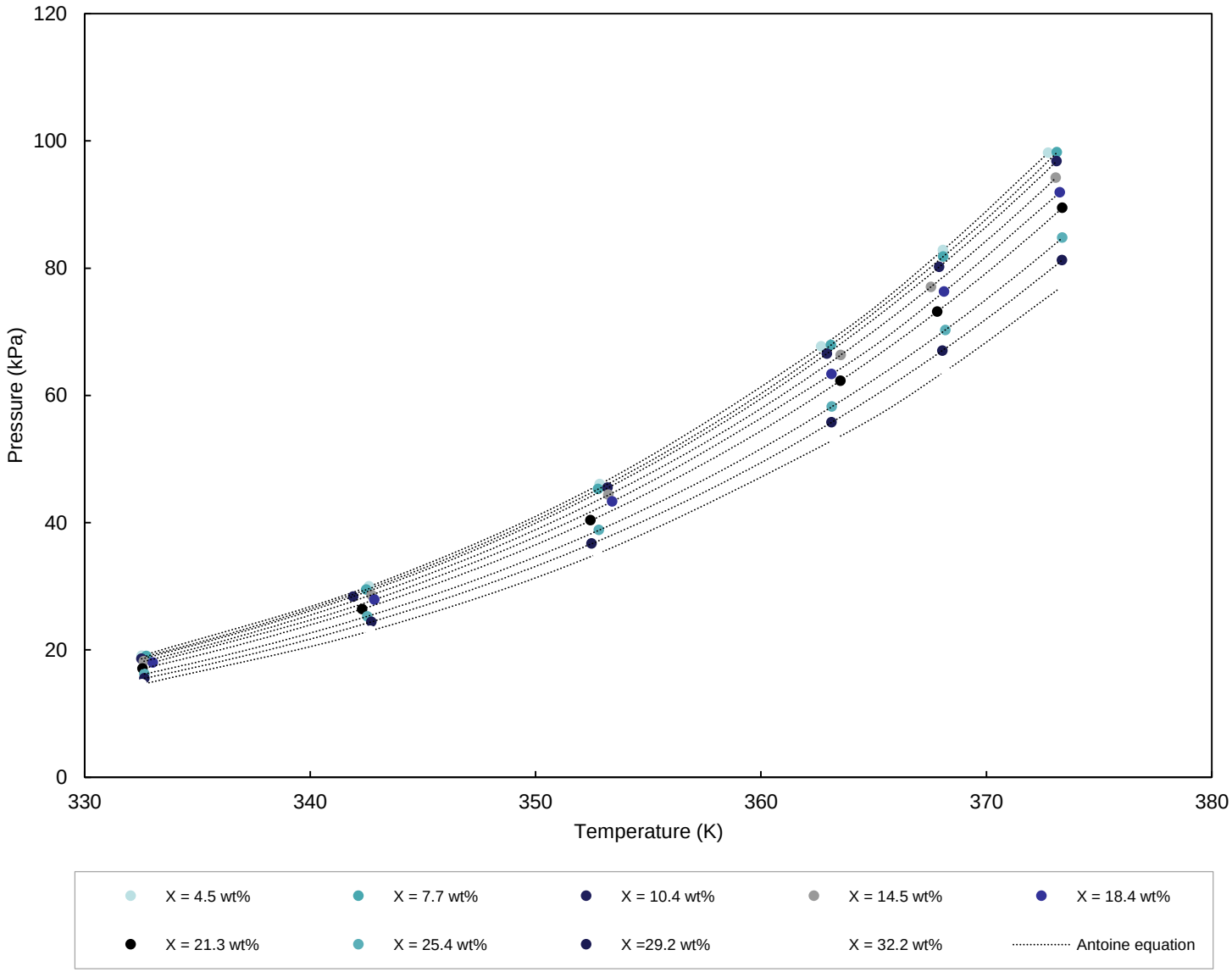
Density

$$\rho - \rho_{H_2O} = A - BT - CT^2$$

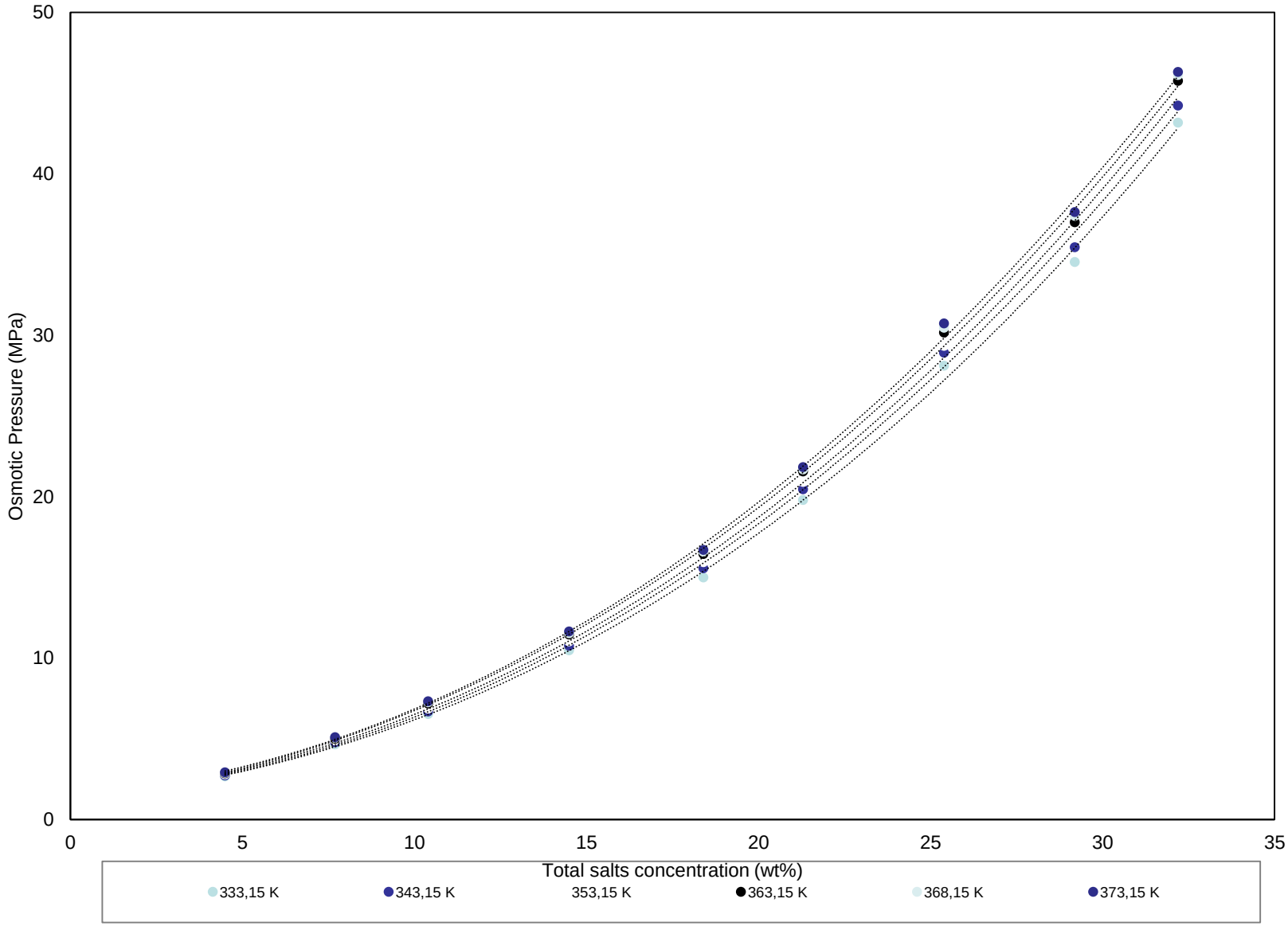
Electrical Conductivity

$$\kappa = (641.2 + 28.3T)X - (95.3 - 74.6T)X^2 - (1903 + 87.8T)X^3$$

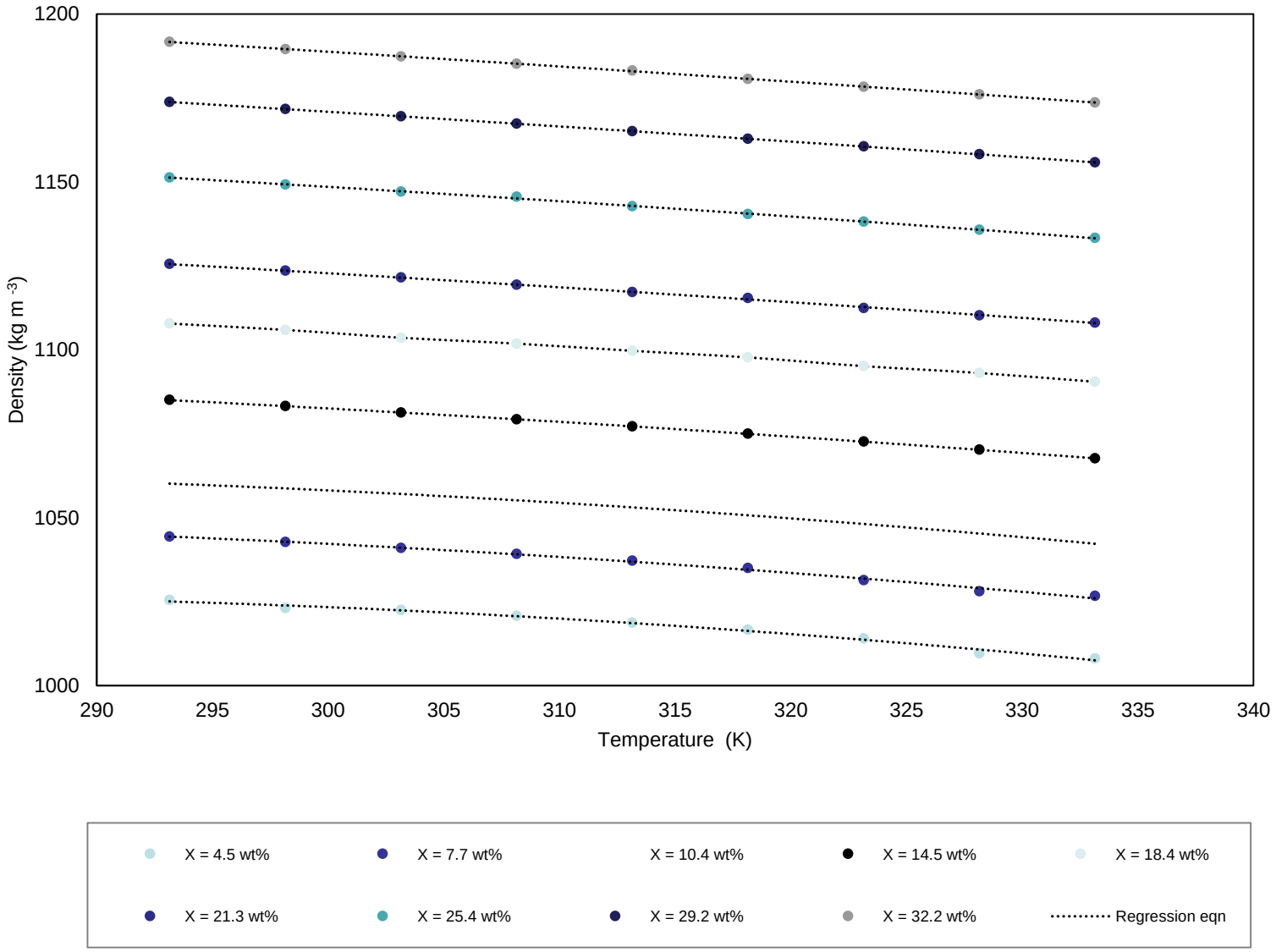
Variations in urine vapour pressure with temperature and concentration



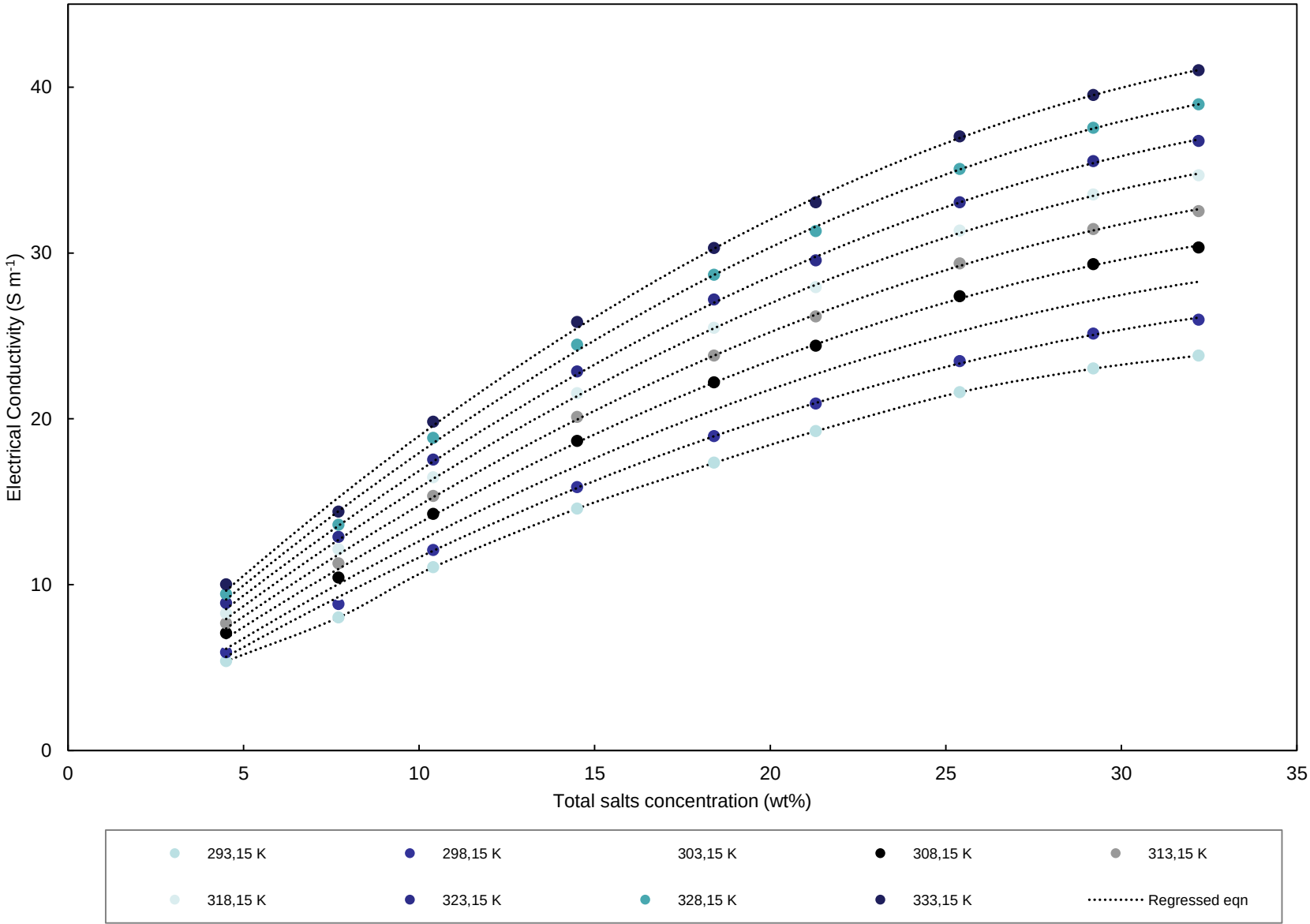
Variations in urine osmotic pressure with temperature and concentration



Variations in urine density with temperature and concentration

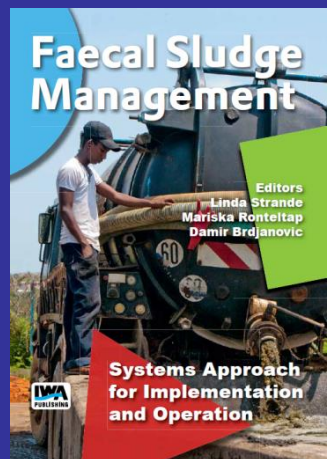


Variations in urine electrical conductivity with temperature and concentration



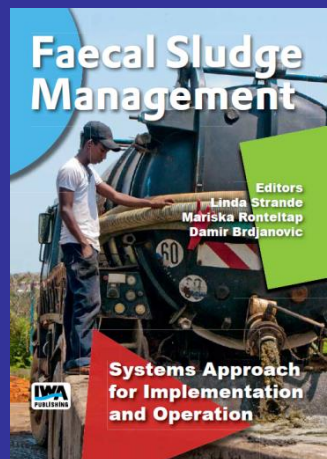
Public toilet and septic tanks

Ratios (g/g)	Public toilets	Septic tanks	Medium strength municipal wastewater
VSS:TSS	0.65-0.68	0.50-0.73	0.60-0.80
COD:BOD_5	5.0	1.43-3.0	2.0-2.5
COD:TKN	0.10	1.2-7.8	8-12
BOD_5:TKN	2.2	0.84-2.6	4-6
COD:TP	109	8.0-52	35-45
BOD_5:TP	17	5.6-17.3	15-20



Reported characteristics of faecal sludge from onsite sanitation facilities and wastewater sludge

Parameter	FS source		WWTP sludge	Reference
	Public toilet	Septic tank		
pH	1.5-12.6			USEPA (1994)
	6.55-9.34			Kengne *et al.* (2011)
Total Solids, TS (mg/L)	52,500	12,000-35,000	–	Koné and Strauss (2004)
	30,000	22,000	–	NWSC (2008)
		34,106		USEPA (1994)
	≥3.5%	<3%	<1%	Heinss *et al.* (1998)
Total Volatile Solids, TVS (as % of TS)	68	50-73	-	Koné and Strauss (2004)
	65	45	-	NWSC (2008)
COD (mg/L)	49,000	1,200-7,800	-	Koné and Strauss (2004)
	30,000	10,000	7-608	NWSC (2008)
	20,000-50,000	<10,000	500-2,500	Heinss *et al.* (1998)
BOD (mg/L)	7,600	840-2,600	-	Koné and Strauss (2004)
	-	-	20-229	NWSC (2008)
Total Nitrogen, TN (mg/L)	-	190-300	-	Koné and Strauss (2004)
			32-250	NWSC (2008)
Total Kjeldahl Nitrogen, TKN (mg/L)	3,400	1,000	-	Katukiza *et al.* (2012)
NH_4-N (mg/L)	3,300	150-1,200	-	Koné and Strauss (2004)
	2,000	400	2-168	NWSC (2008)
	2,000-5,000	<1,000	30-70	Heinss *et al.* (1998)
Nitrates, NO_3^- (mg N/L)	-	0.2-21	-	Koottatep *et al.* (2005)
Total Phosphorus, TP (mg P/L)	450	150	9-63	NWSC (2008)
Faecal coliforms (cfu/100 mL)	$1x10^5$	$1x10^5$	$6.3x10^4$ - $6.6x10^5$	NWSC (2008)
Helminth eggs (Numbers/L)	2,500	4,000-5,700	-	Heinss *et al.* (1994)
	20,000-60,000	4,000	300-2,000	Heinss *et al.* (1998)
		600-6,000		Ingallinella *et al.* (2002)
		16,000		Yen-Phi *et al.* (2010)

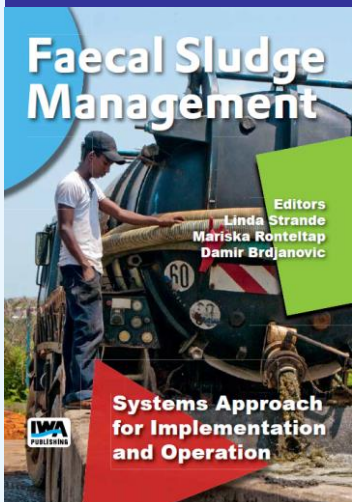


Trash

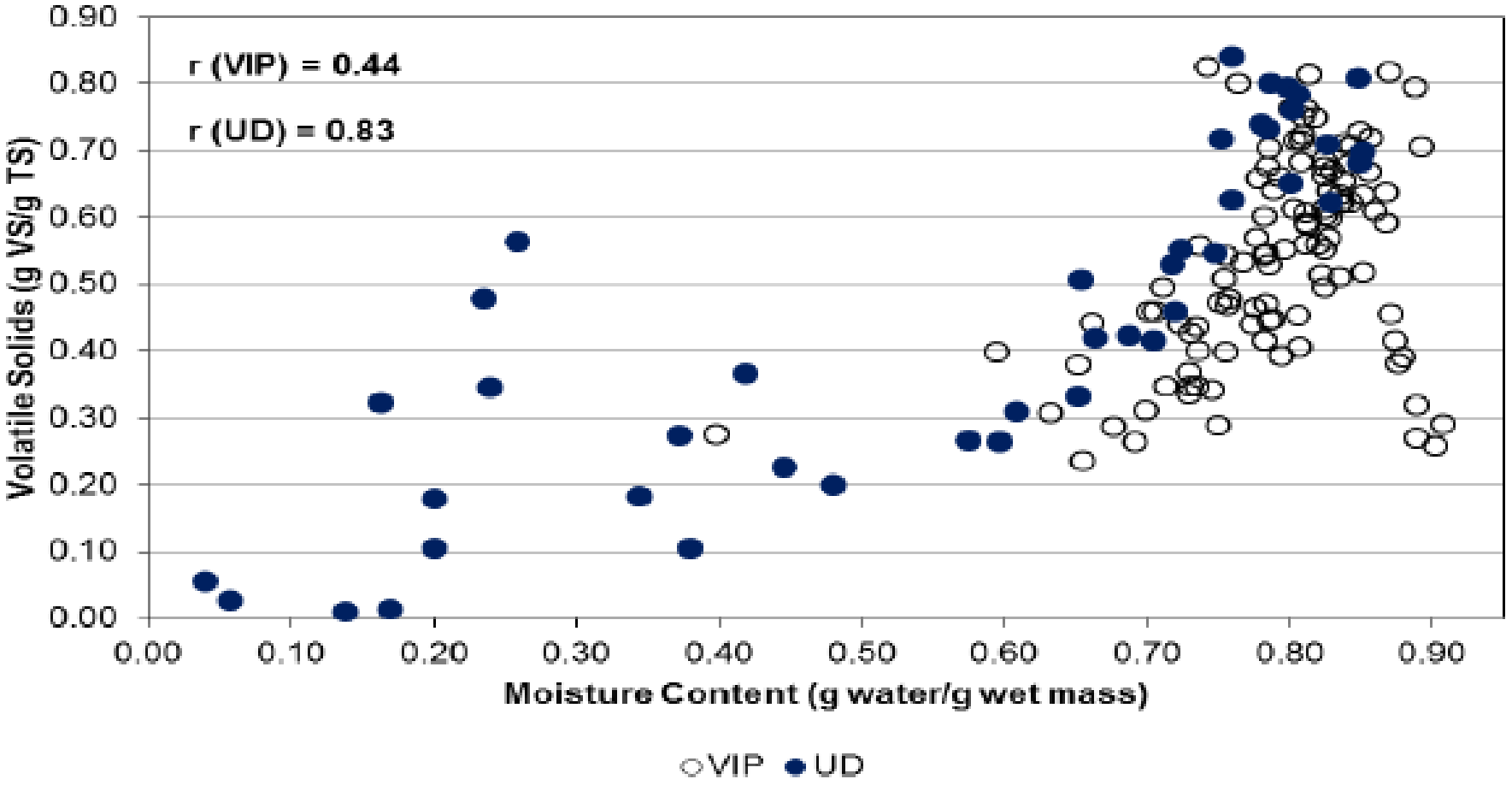
Screenings from the Niayes faecal sludge treatment plant in Dakar, Senegal (photo: Linda Strande). Faecal Sludge Management: A systems approach for implementation and operation

VIP analysis - Durban

Type	Moisture	SS	VSS	Ash	SVI	pH	COD	NH_4-N	TKN	PO_4-P	P_{tot}	Thermal conductivity	Calorific value	Density
	%	mg/L	g/g DW	g/g DW	ml/mg	-	mg/g DW	mg/g DW	mg/g DS	mg/L	mg/L	W/mK	MJ/kg	kg/m³
Dry VIP	83	381	0.57	0.43	0.11	7.6	680	13	40	0.73	3.86	0.54	14.06	1,356.5
Wet VIP	79	562	0.54	0.46	0.04	7.7	720	7	30	0.83	2.93	0.55	13.08	1,443.1
CAB VIP	77	139	0.49	0.51	0.51	7.4	650	3	30			0.60	14.31	1,350.1
UD	60	246	0.45	0.55	0.23	7.5	490	5	30	1.00	3.27	0.38	12.93	1,450.4

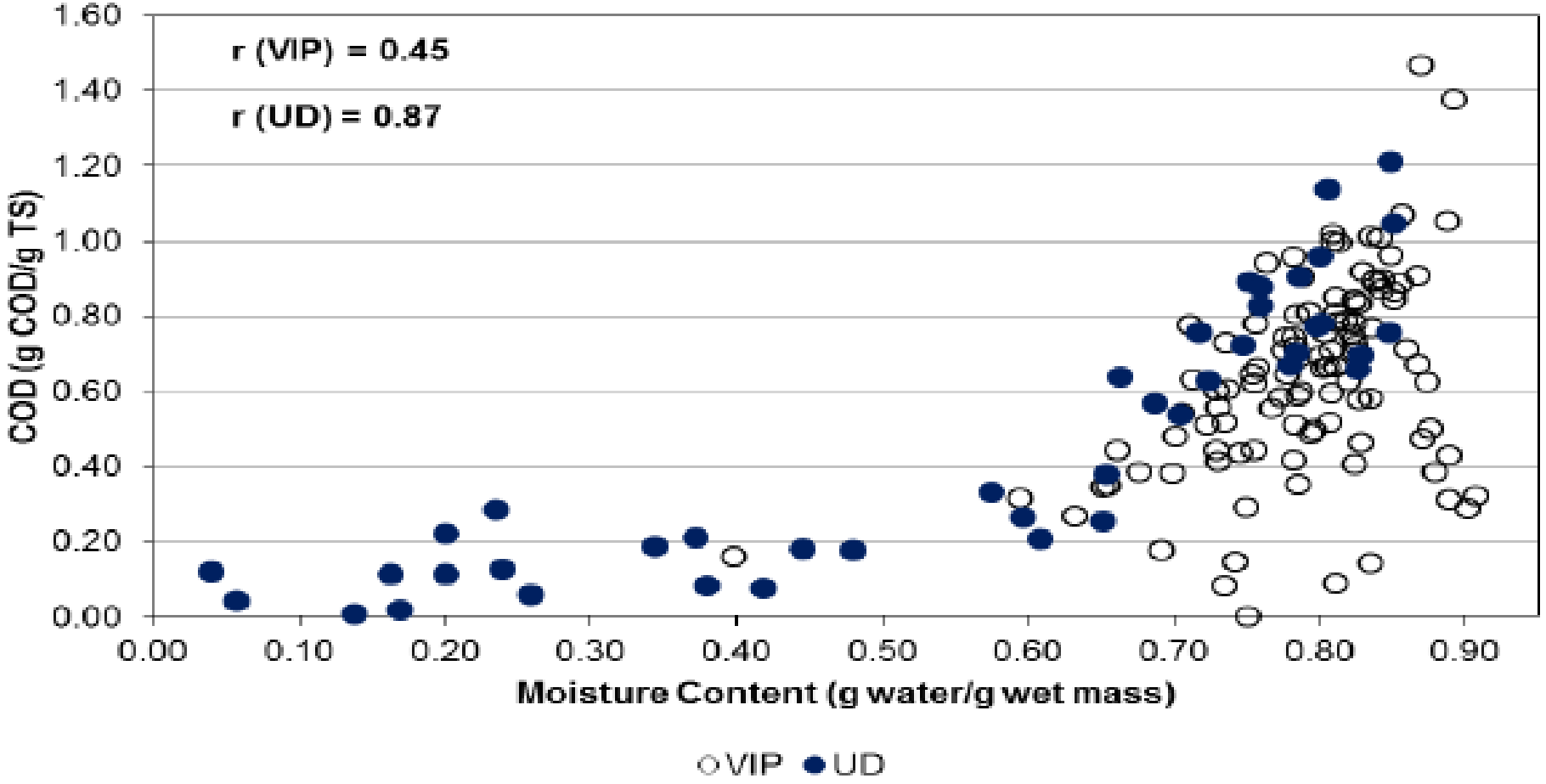


VIP and UD toilets – volatile solids and moisture content



Zuma, L 2015. MScEng dissertation, University of KwaZulu-Natal (submitted)

VIP and UD toilets – COD and moisture content



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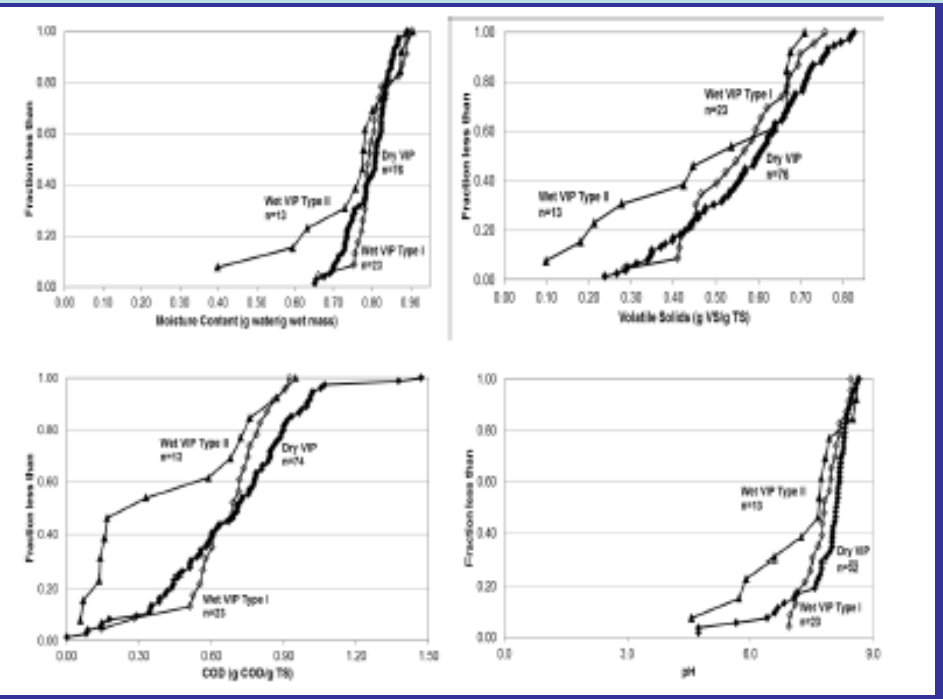
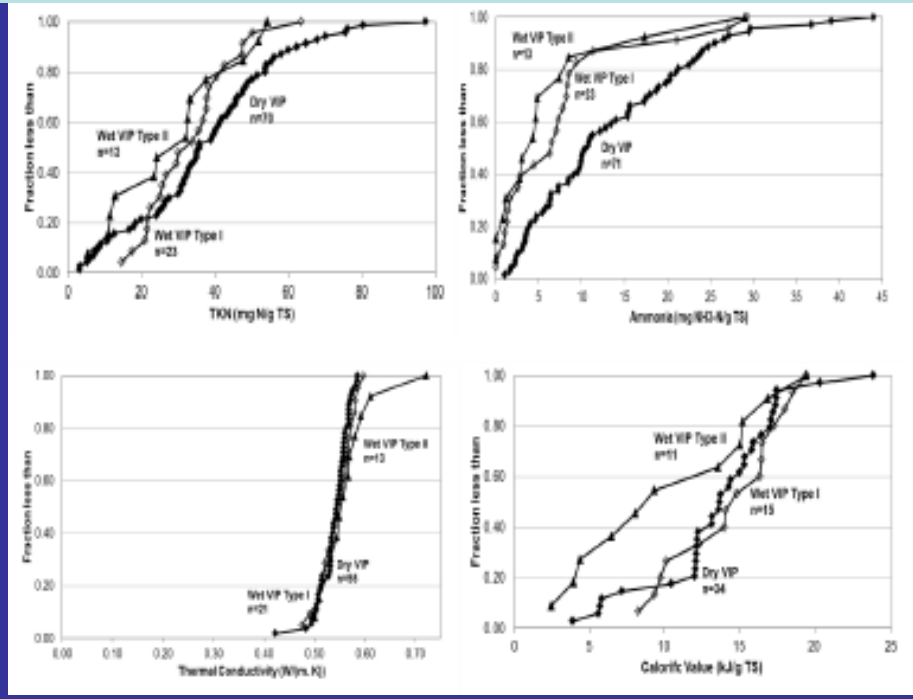
Dry and wet VIPs – moisture, volatile solids, COD, pH NH_4 TKN thermal conductivity and calorific value





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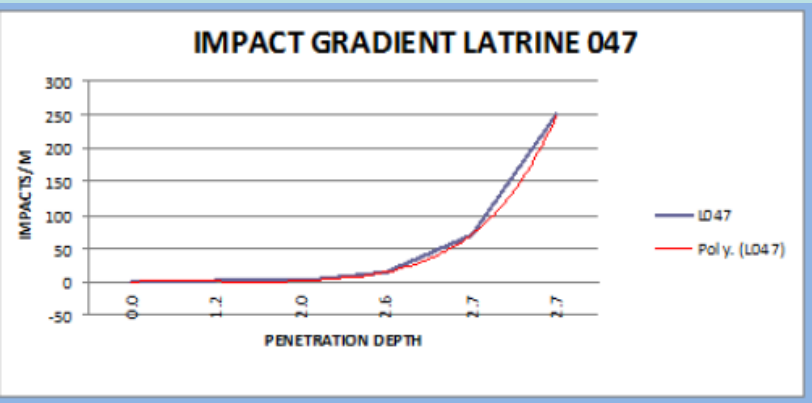
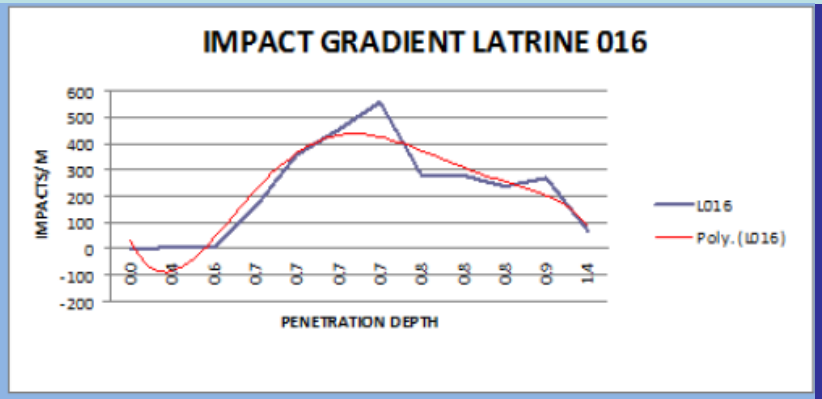
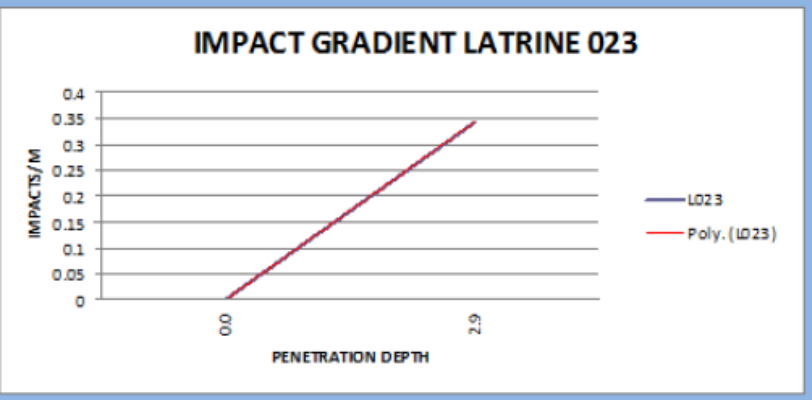
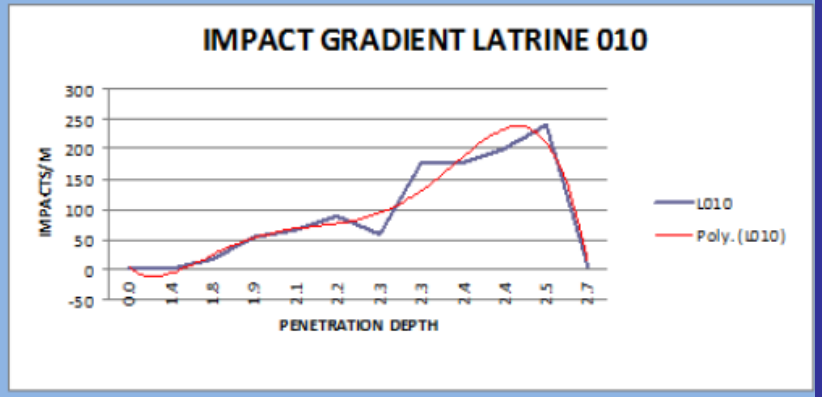
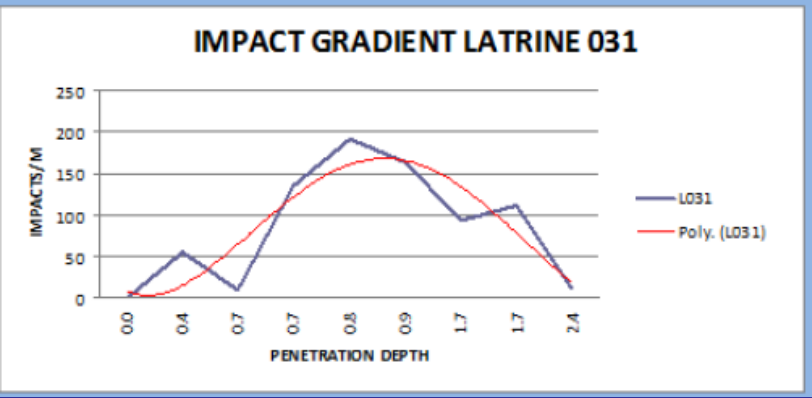
Penetrometer and VIPs (i)

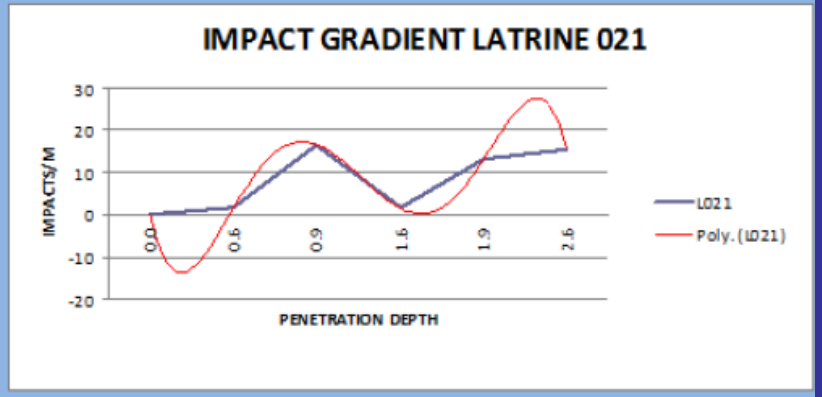




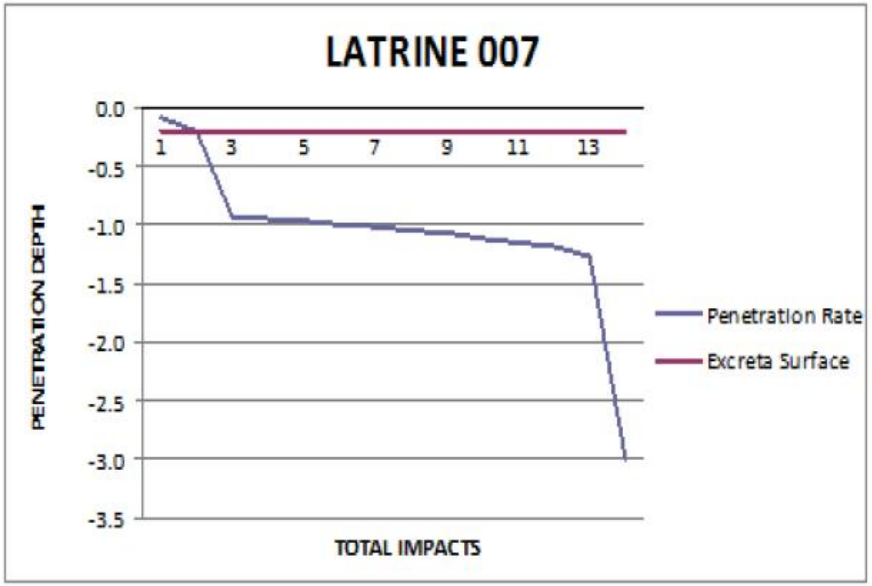


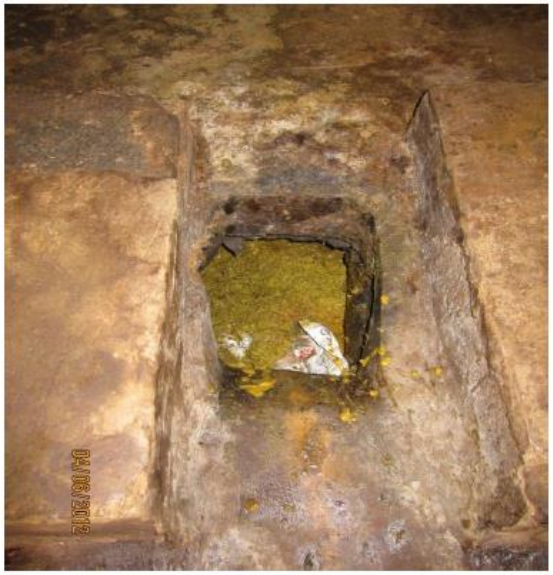






Penetrometer and VIPs (ii)





Samples taken from a single pit latrine

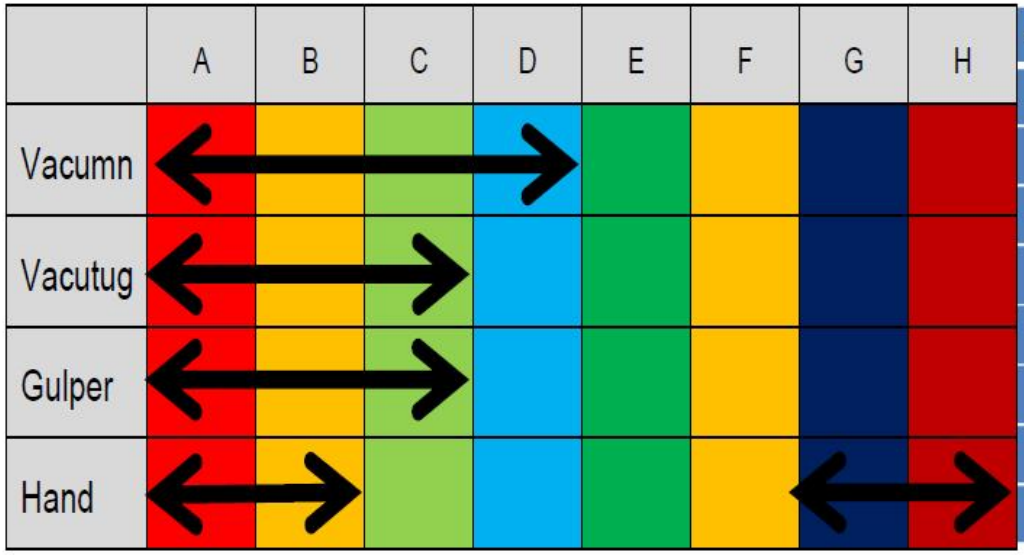
By hand at 1 m

Approx 1.4 m

By Gulper at 2 m

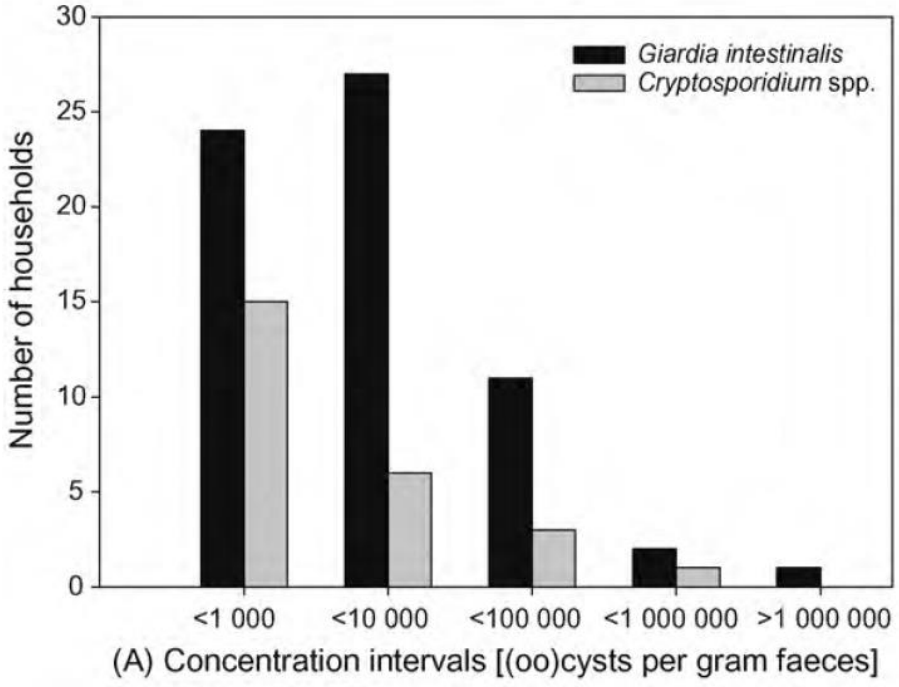
Penetrometer and VIPs (iii)

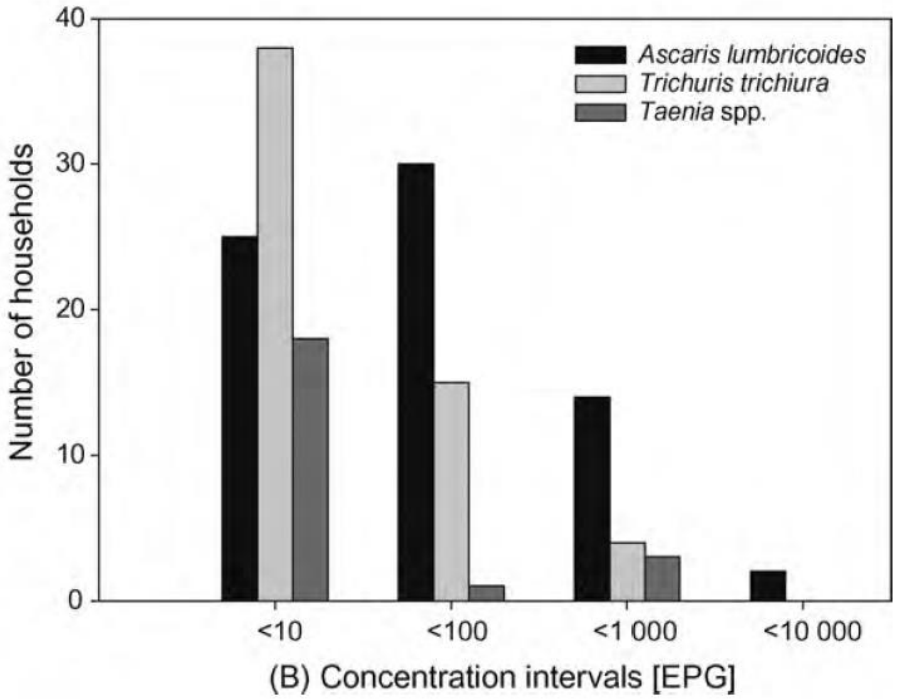
Theoretical De-sludging Equipment Catagorization



Category	Number of Impacts/1 m
A	<=0
B	1-5
C	6-20
D	21-50
E	50-100
F	100-200
G	201-300
H	>300

Helminths in VIP toilets in Durban





Distribution of the concentrations for samples positive for (A) G. intestinalis and Cryptosporidium spp. and (B) the helminths.

Transactions of the Royal Society of Tropical Medicine and Hygiene 104 (2010) 646–652

Helminths

- indicator of pathogen content
- possibly requires spiking
- need to determine if eggs are viable
- interferences
- pit emptiers
  - viable ova left on the ground after emptying
    - mean 8 500; max 184 000
- viable ova left on hands of waste handlers
    - mean 90; max 2 300

VIP sludge drying

Diffusivity: 7.8×10^{-8} - 2.1×10^{-7} m^2/s

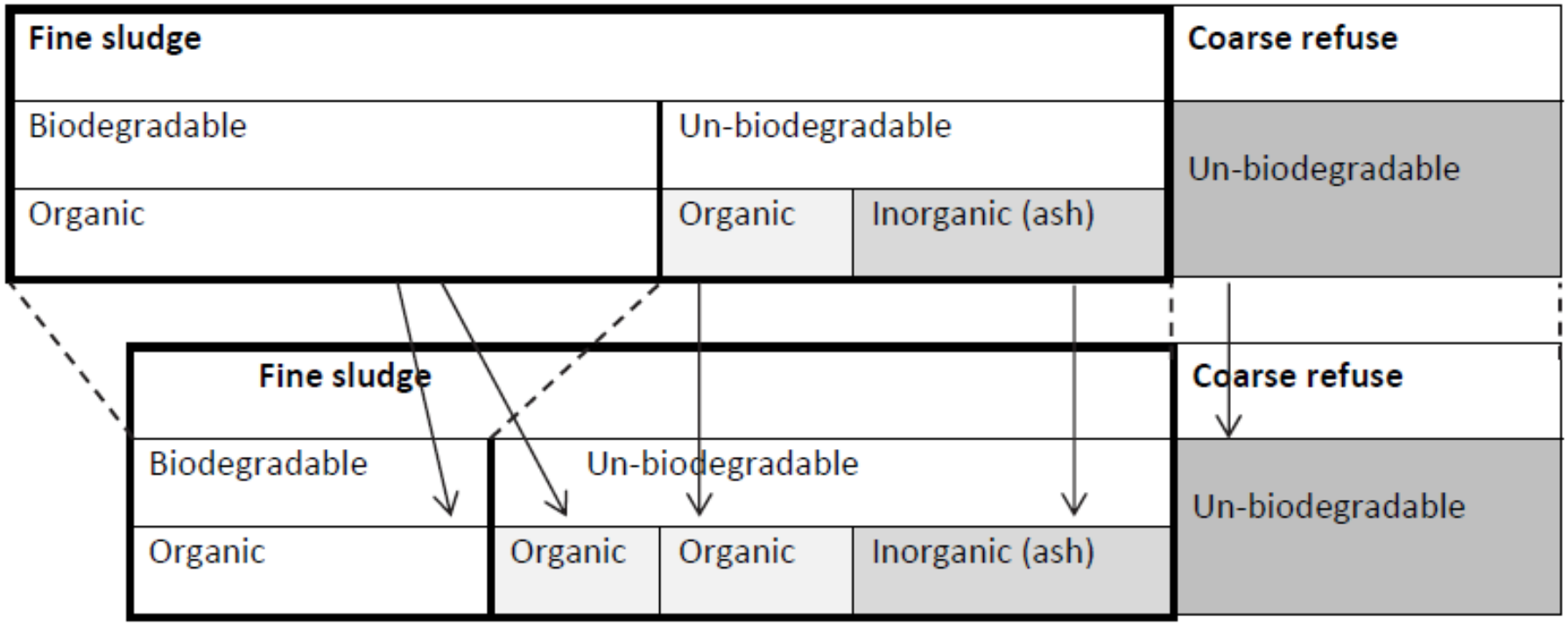
Thermal conductivity : 55 W/m.K (79% moisture)

0.04 W/m.K (dry)

Calorific value: 11 to 13 MJ/kg sample

VIP sludge degradation

- Trash can be 25% of the volume
- Biodegradability decreases with depth



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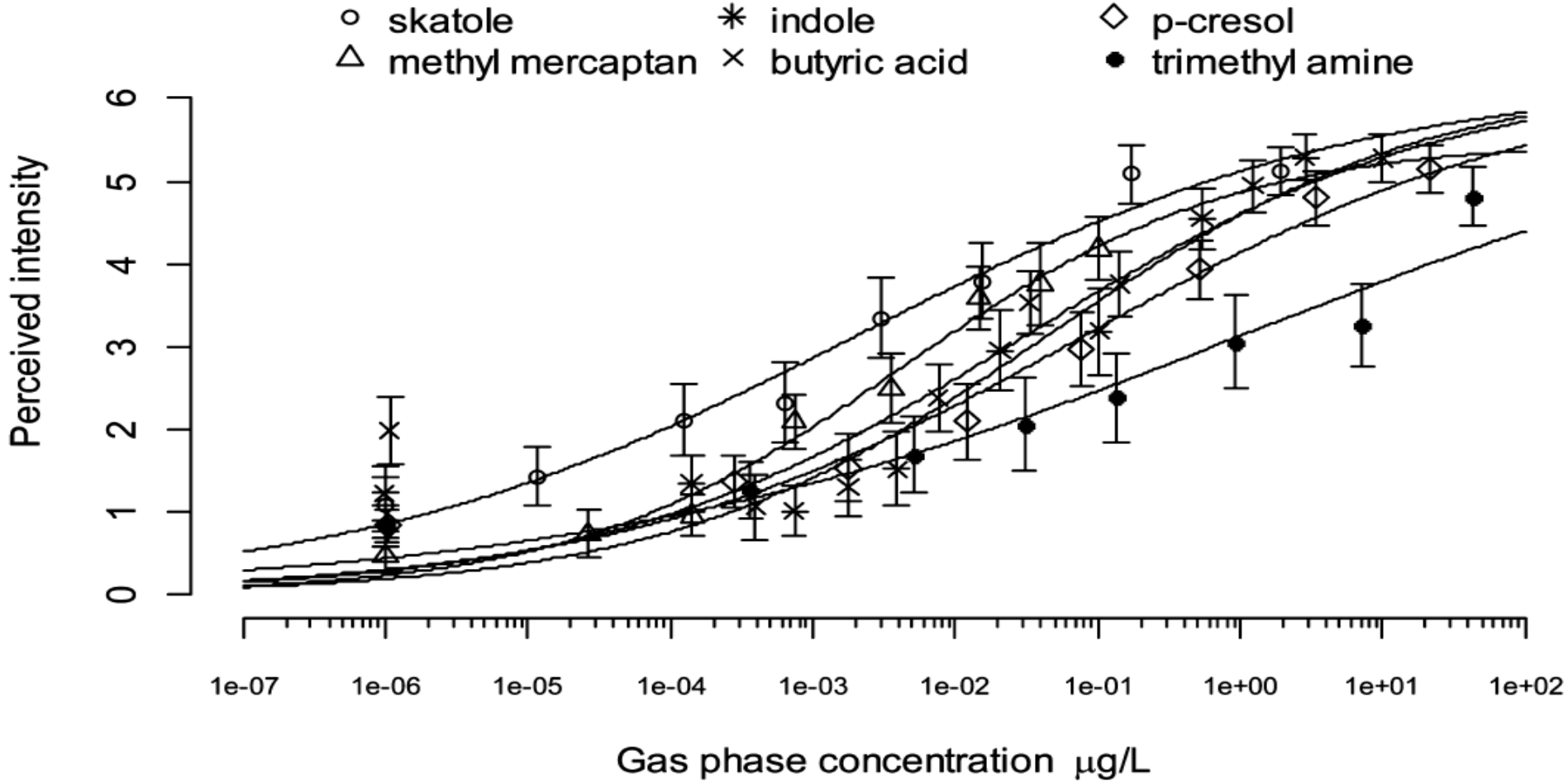
Odour – perceived intensity



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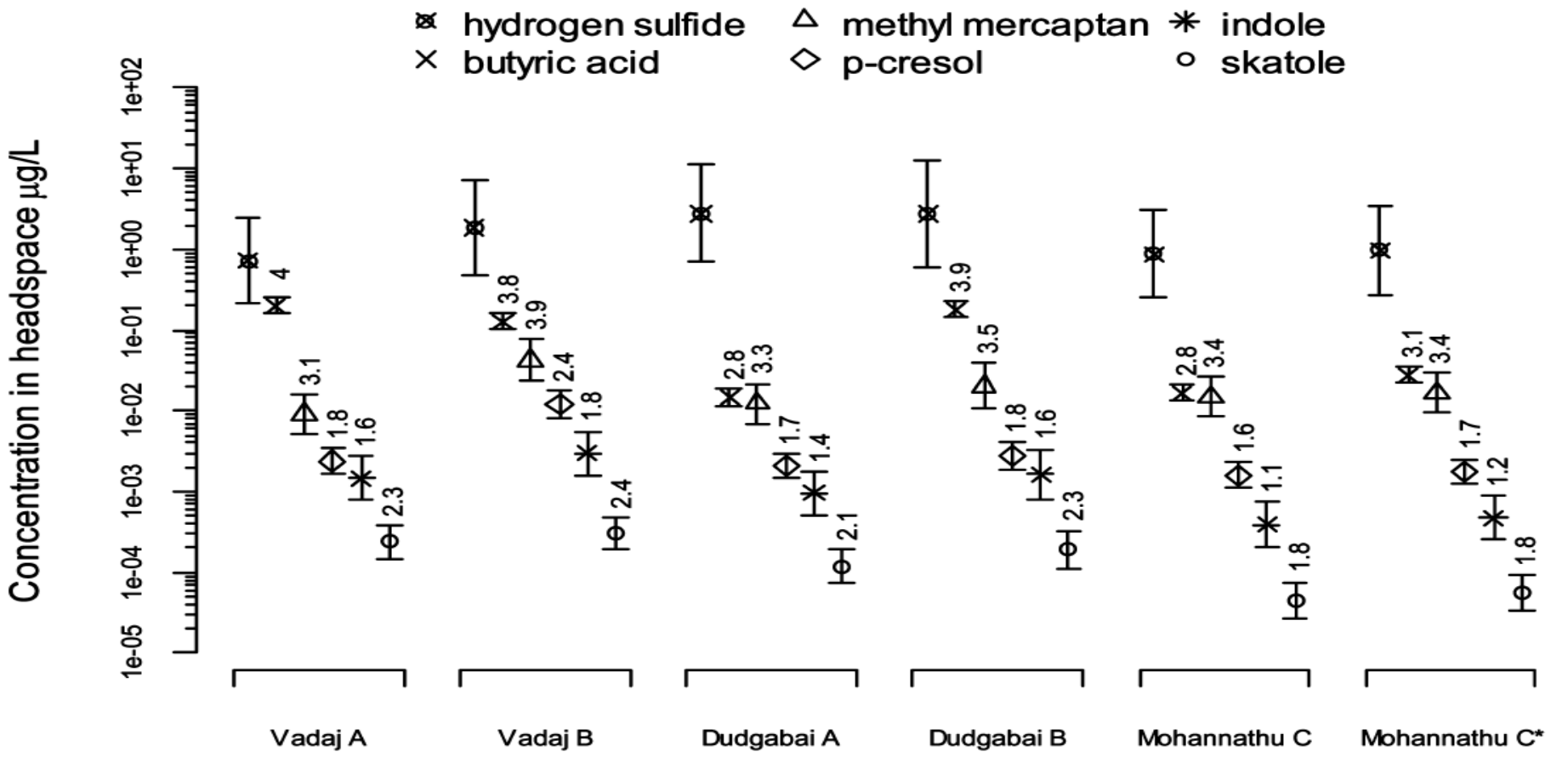
Quantitative Headspace Analysis of Selected Odorants from Latrines in Africa and India

Charles Jean-François Chappuis, Yvan Niclass, Christine Vuilleumier, and Christian Starkenmann*
Corporate R&D Division, Firmenich SA, P.O. Box 239, CH-1211 Geneva 8, Switzerland

Odour concentration and intensity - India



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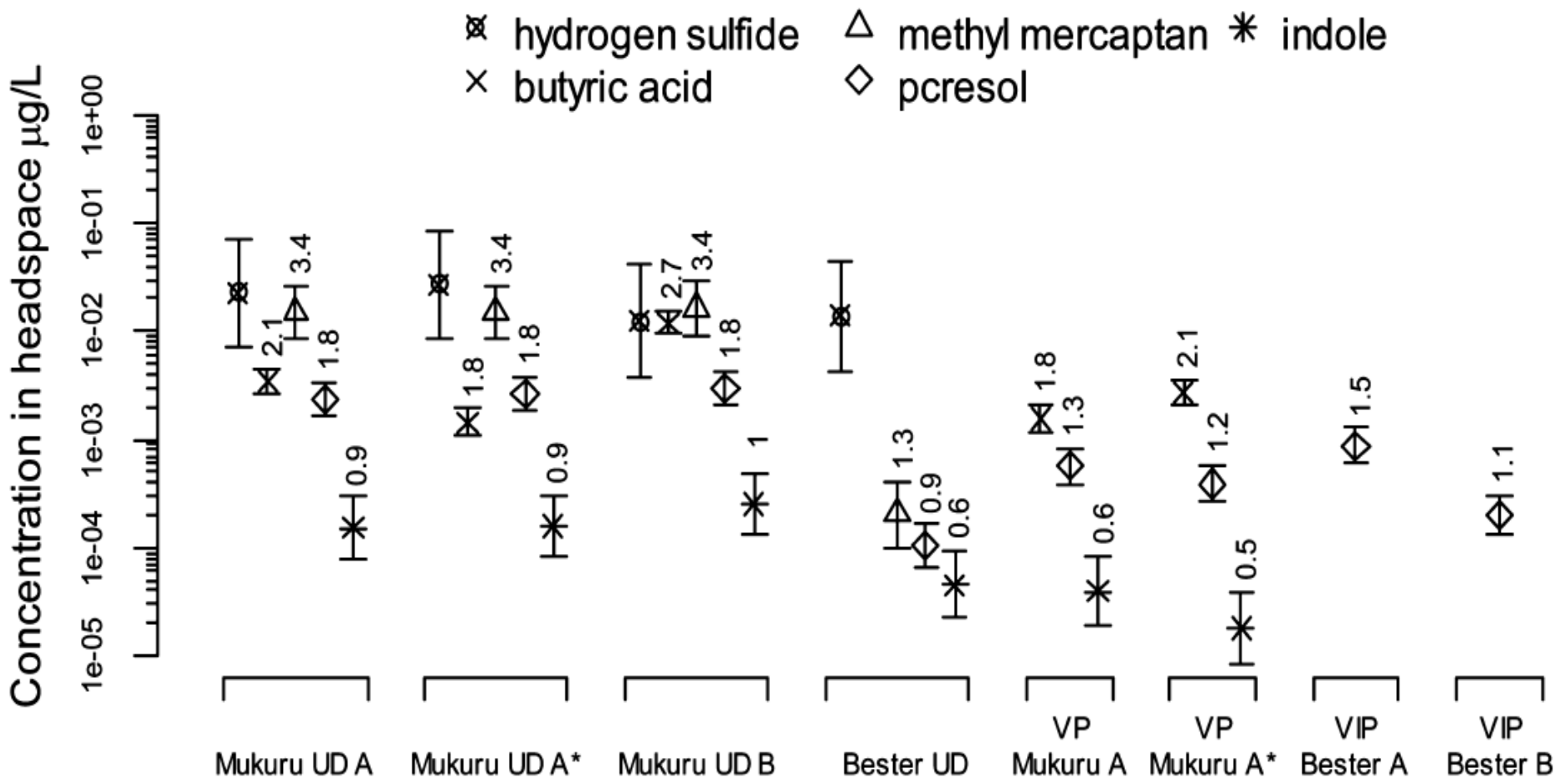
Odour concentration and intensity - Africa



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Other aspects to consider

- Need for ***Standard Methods***
- Sampling
- Sample preservation and transboundary transport
- Safety, heath and hygiene
- Ethics and permissions
- Analyses from other regions
- Other faecal sludge laboratories are being set up
- Extend the range of analyses

Typical view of a pit – where on the Bristol Stool chart?

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