Respect the Rheology!

Thickened Biosolids Pumping for Beneficial Reuse in Columbus, Ohio

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Brown AND Caldwell

Agenda

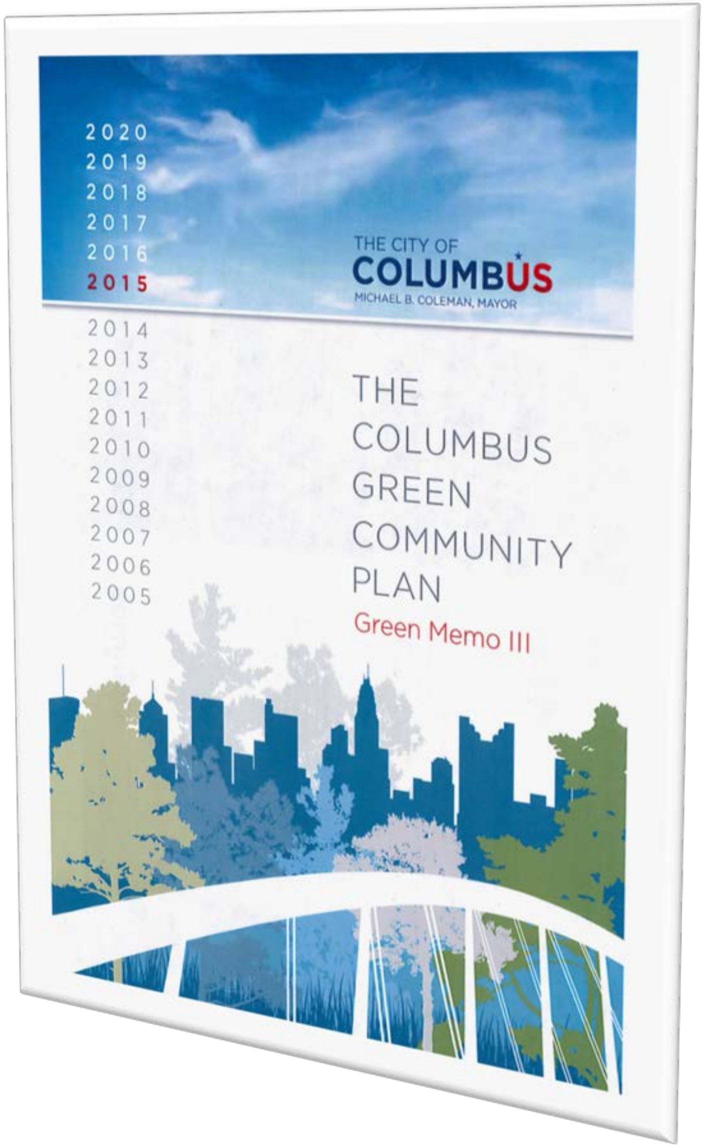
- Overview of Columbus Biosolids Land Application Program/Project
- Sludge Pumping Design Practices
- Rheology 101
- Southerly WWTP Biosolids Land App Project
  - Field Testing
  - Rheology Testing
- Results and Startup

Overview of Columbus Biosolids Land Application Program

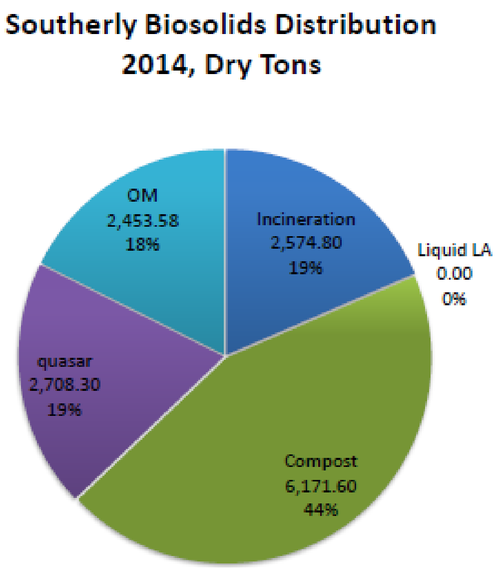
THE CITY OF
COLUMBUS
ANDREW J. GINTHER, MAYOR
DEPARTMENT OF
PUBLIC UTILITIES

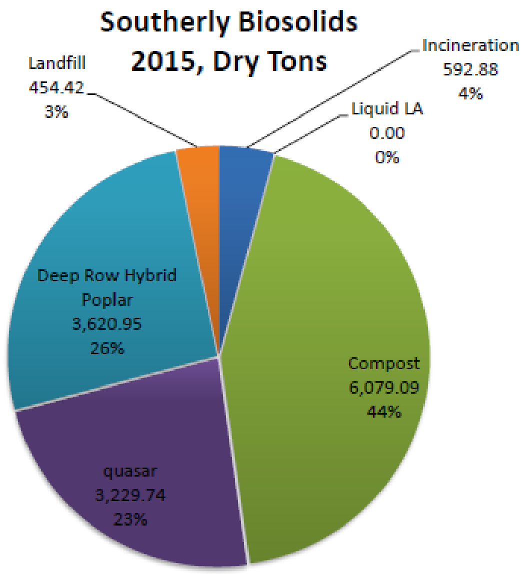
Columbus Sustainability Goals

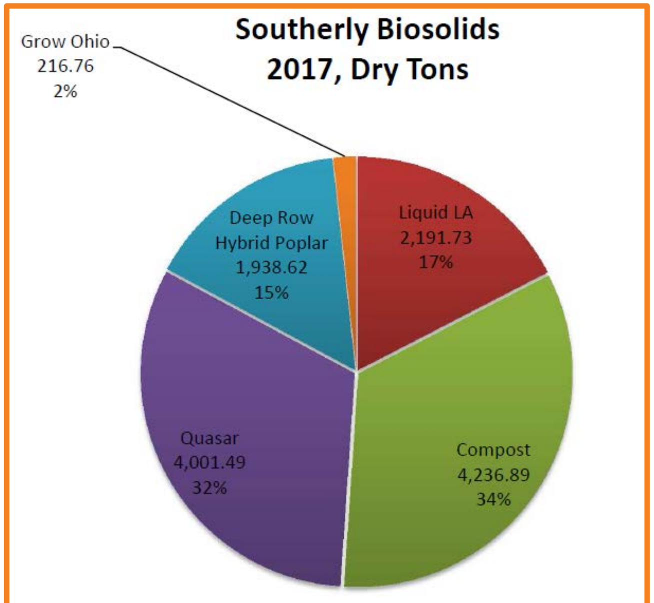
- City sustainability goals described in the "Green Memo"
- Focus on conservation, efficiency, and renewables/reuse
- "Eliminate use of incinerators at Southerly WWTP…"



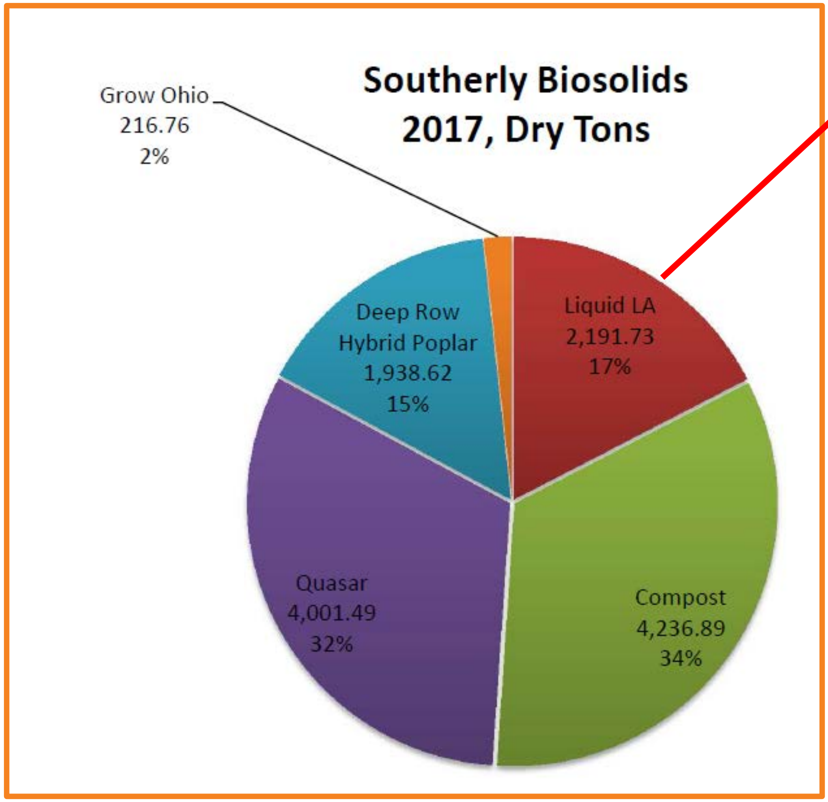
Southerly WWTP Solids Disposal







SWWTP: 2017 (data through November)



- Liquid Land Application
  - 9,070,000 gallons
  - 37,400 wet tons
  - In Storage – 96,000 gallons

Biosolids Land Application

- Overview of BLAF project
  - 8 Mgal of storage for thickened biosolids
  - Truck loading station
  - Pump/control building for truck load out
  - Repurposed centrifuges/new thickened biosolids pumps
- Thickened biosolids:
  - Centrifuge thickened with polymer addition to 8-10% TS.

Truck Loading Station

BLAF Facilities

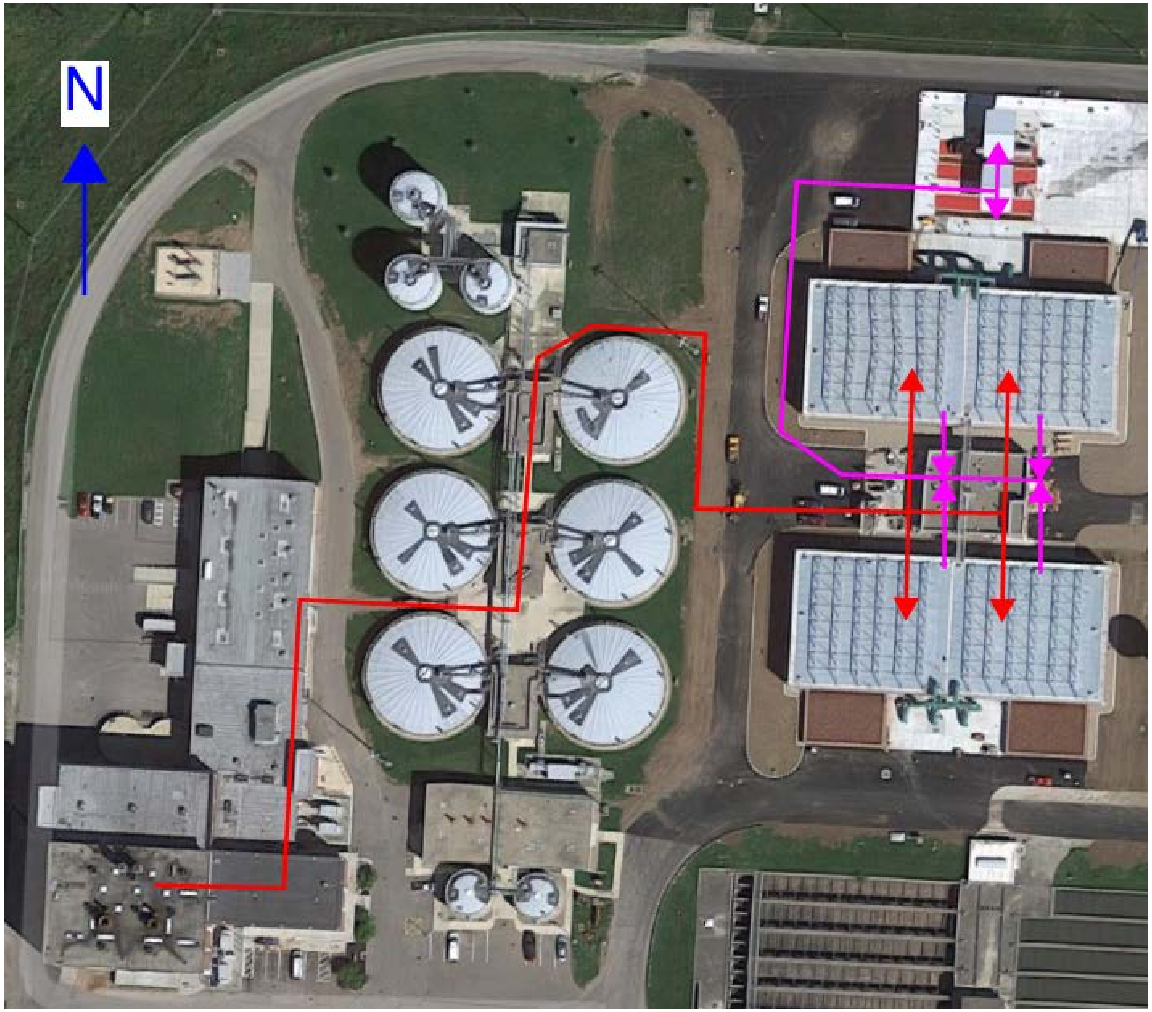
Two Thickened Biosolids (TBS) Pumping Systems Designed

TBS Transfer Pump

- From centrifuges to storage tanks

Truck Loading/ Recirculation

- From tanks to truck loading, tank recirculation



The 8-million gallon question:

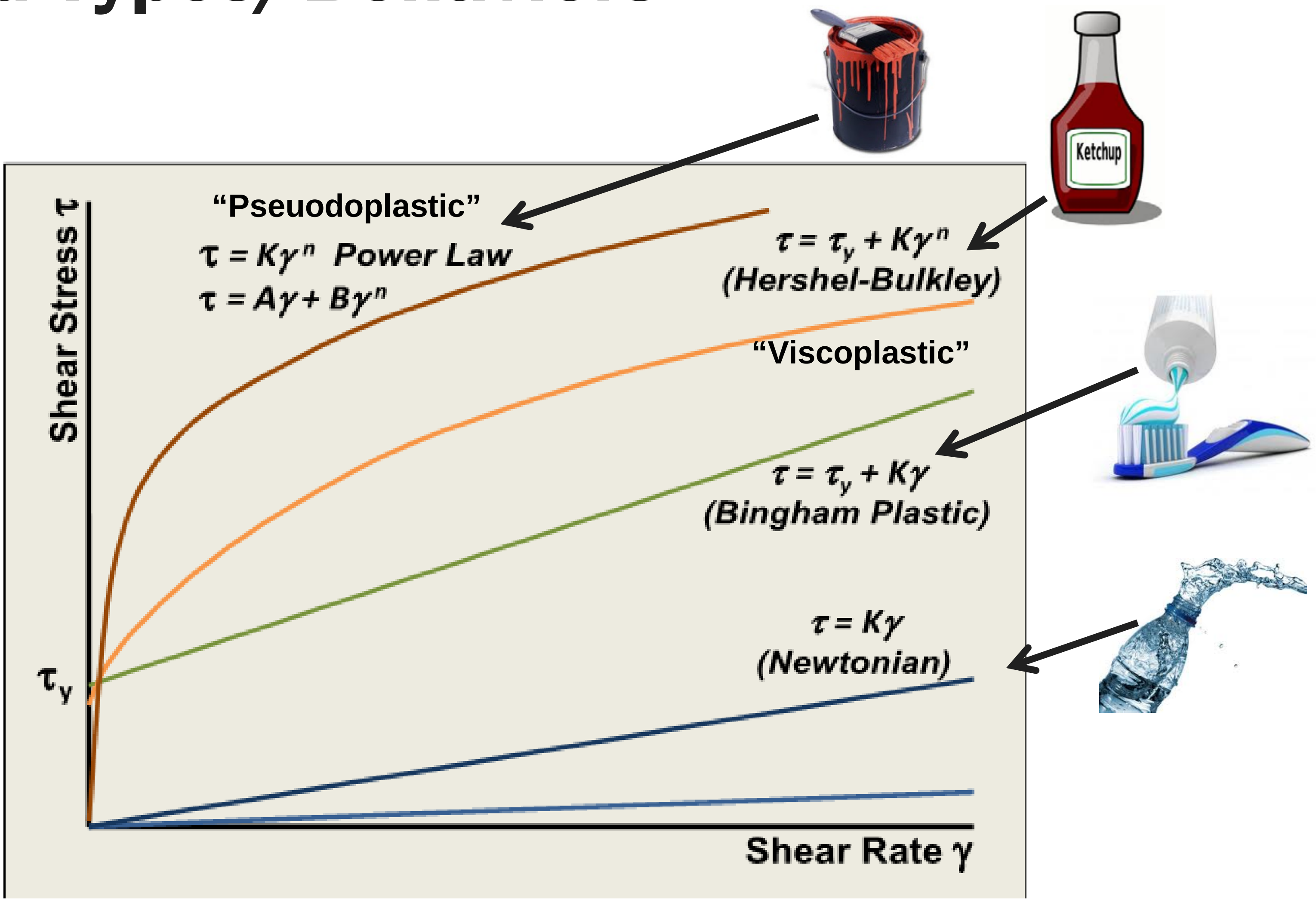
- How are we going to move this stuff (10%TS Biosolids)?
  - Not dry/typical cake %TS
  - Very thick (for a "liquid"), non-Newtonian characteristics.

The 8-million gallon question:

First… a little Rheology 101

- Newtonian Fluid: viscosity constant, independent of shear rate (water).
- Non-Newtonian: viscosity not constant with change in shear rate (Literature says wastewater sludge once solids concentration >~2%).
- Shear-thinning: viscosity decreases as shear-rate increases.
- Yield Stress: minimum amount of force (shear) applied to initiate flow.
- Thixotropy: viscosity decreases over time when constant shear is applied.

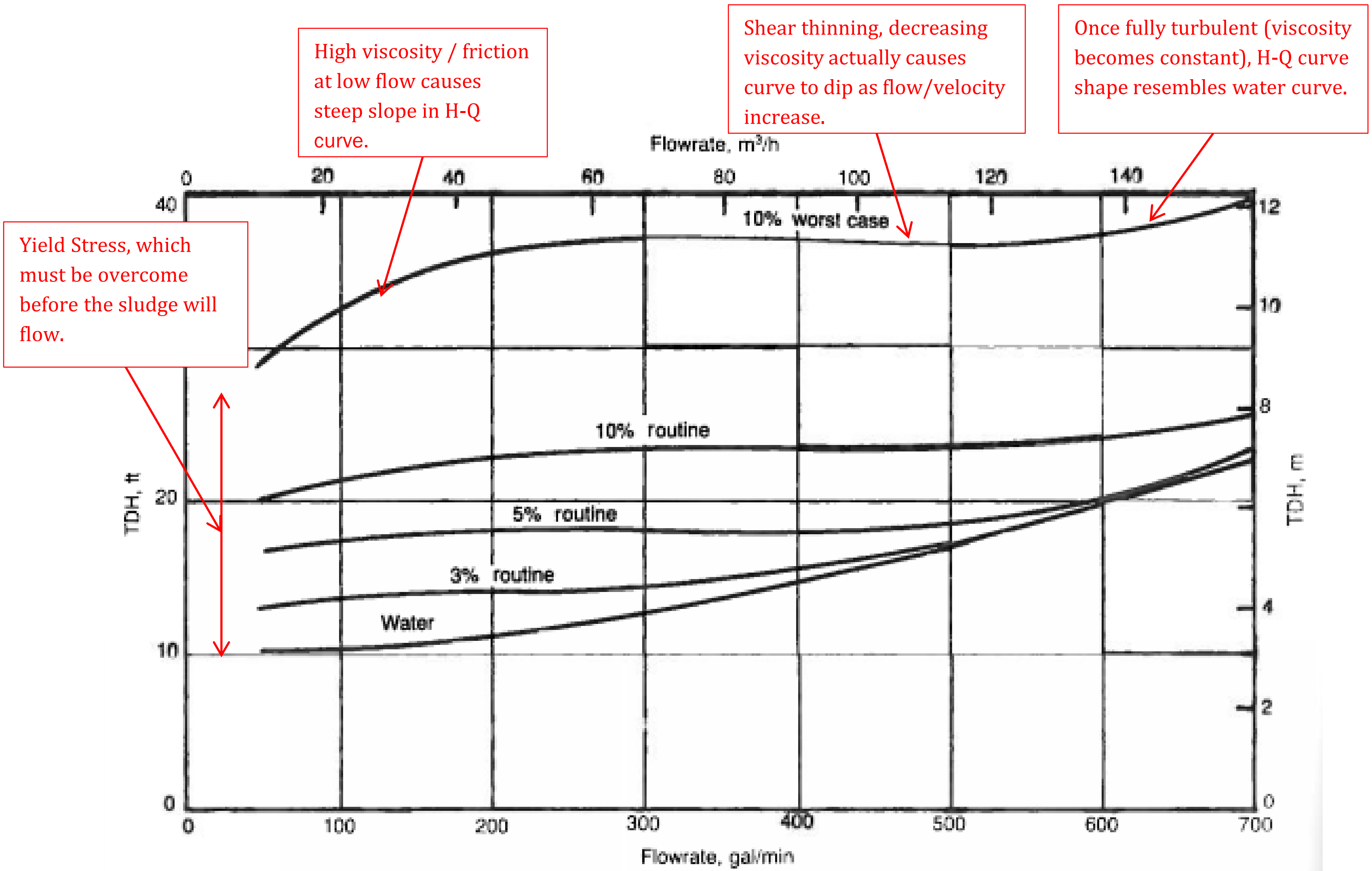
Fluid Types/Behaviors



What do we know about biosolids?

- Review of literature suggests digested sludge acts like a viscoplastic.
  - Shear-thinning
  - Yield stress

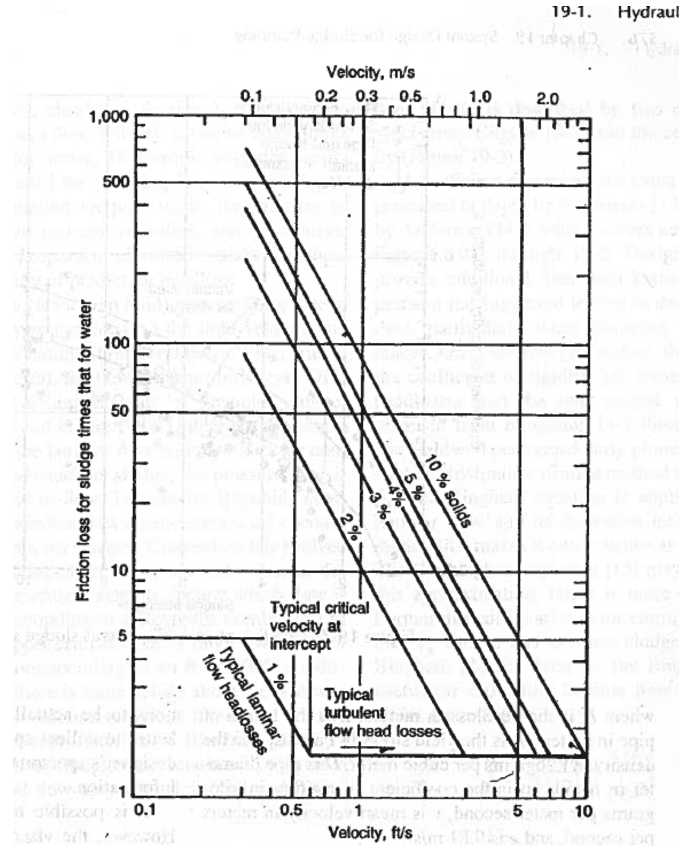
What does that look like on system curve?



Let's hit the books…

- Pumping Station Design (Sanks)
  - Underlying theory/equations
  - Pump types
  - Design procedures

- "Mulbargar Curves"



19-4. Recommended design curves. Headloss prediction for worst-case design.

- Acknowledges uncertainty in sludge friction loss calculations and recommends adjusting factors upward by "50% or more" for atypical sludges.

What did we come up with?

- Textbook – "Mulbargar" approach (based on 10% TS):

Parameter	TBS Transfer
Flow (gpm)	135
Pressure (psi)	75
Motor size, calculated (hp)	20
Motor size, selected (hp)	40

Parameter	Truck Loading
Flow (gpm)	500 - 1,000
Pressure (psi)	35 - 45
Motor size, calculated (hp)	60
Motor size, selected (hp)	125

So… we're done, right?

Par[illegible]er	TBS [illegible]fer
F[illegible] ([illegible])	135
[illegible]essure [illegible]	75
[illegible]otor size, [illegible]alculated (hp)	20
[illegible]otor size, [illegible]lected (hp)	40

P[illegible]meter	Truc[illegible]g
Flow [illegible])	50[illegible]00
Pressure ([illegible]	[illegible]5 - 45
[illegible]	[illegible]
Motor size, selected (hp)	125

RESPECT THE RHEOLOGY!

Too much uncertainty in sludge characteristics

- Two-pronged approach to improve our confidence in sludge pumping design:
  - Field testing
  - Rheology testing

Field Testing

- Centrifuge testing/optimization needed to produce 8-10% TS
- Existing thickened sludge pumps (rotary lobes) pumped to Digester 6 (digested sludge storage).
- Flow, pump speed, and manual pressure readings along the flow path. %TS grabs from centrifuges taken.

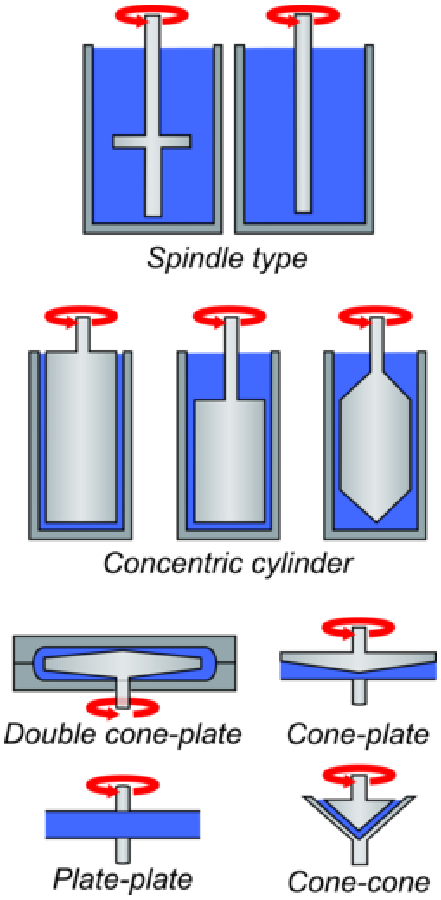
Field Testing - Findings

- Dialing in/maintaining at 9% or 10% is challenging.
- Existing TSPs were not going to be sufficient to pump all the way to the new storage tanks
- Data was noisy.
  - Pump speed, flow, and pressure loss weren't following clear relationship
- Estimated pressure loss roughly based on psi/ft.
  - ~0.05 psi/ft at 55-75 gpm

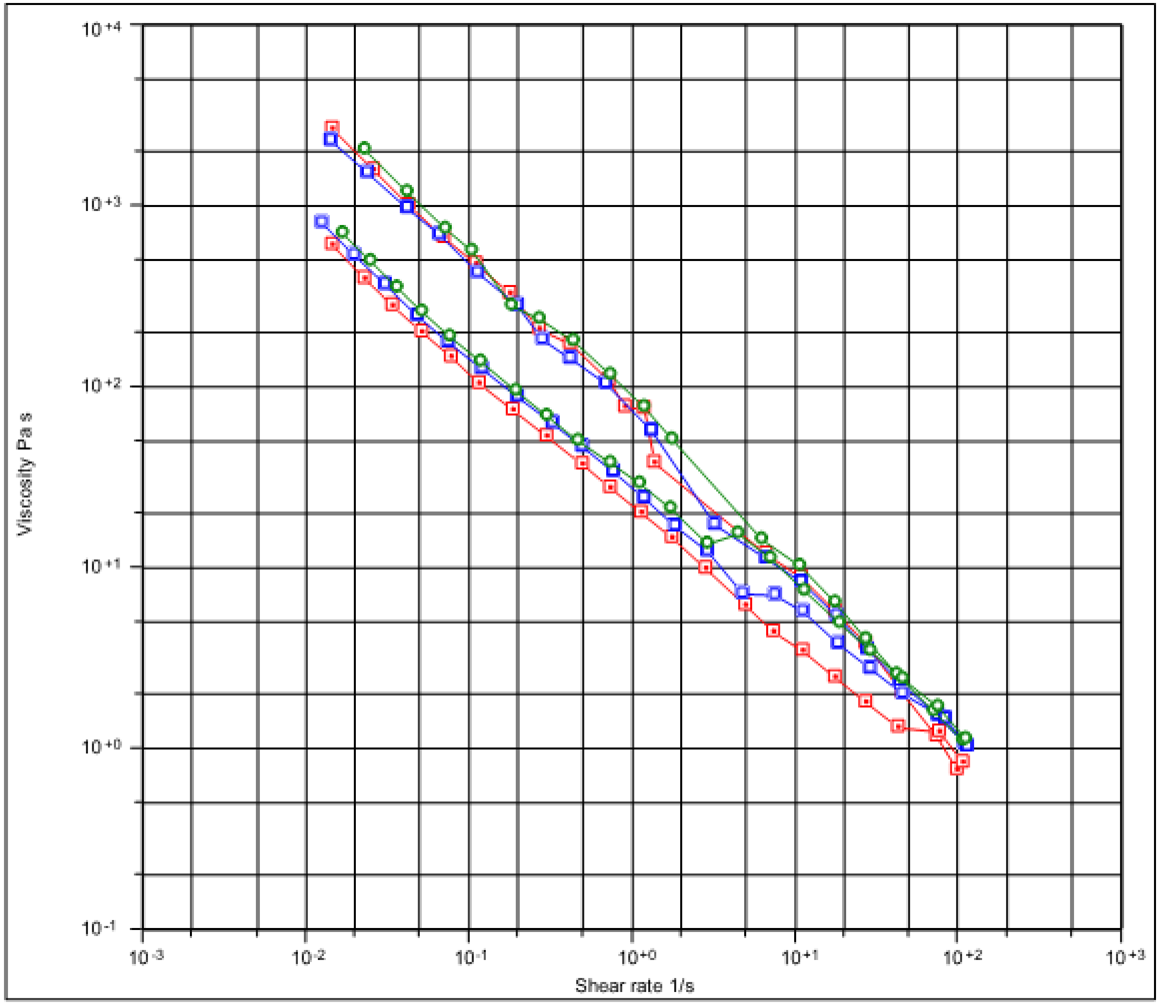
Rheology Analysis

- Field collected samples (at 9.6 %TS) sent to private lab
- Tested at two temperatures (40F and 75F)
- Tested over shear range of 0.01 to 100 s^{-1}
- STRESSTECH Rheometer (cup and bob)

Rheometers


Spindle type
Concentric cylinder
Double cone-plate
Cone-plate
Plate-plate
Cone-cone

Shear Thinning Behavior



Thickened sludge 40F sh rate sweep r1.RSS

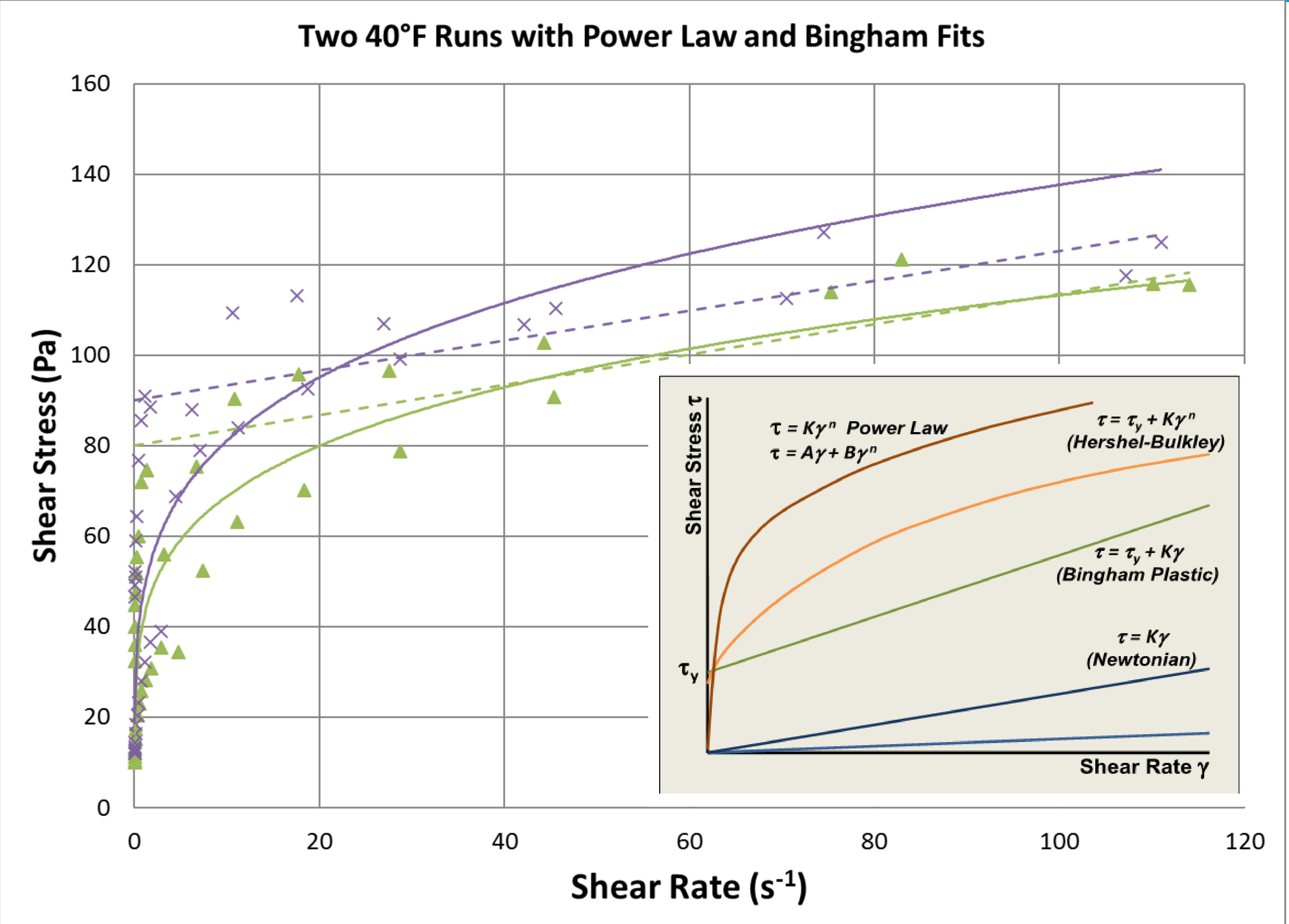
Viscosity

Thickened sludge 40F (Dup) sh rate sweep 1

Viscosity

Thickened sludge 40F (Dup) sh rate sweep 2

Viscosity


Two 40°F Runs with Power Law and Bingham Fits
160
140
120
100
80
60
40
20
0
Shear Stress (Pa)
0
20
40
60
80
100
120
Shear Rate (s-1)
Shear Stress τ
τ = Kγⁿ Power Law
τ = Aγ + Bγⁿ
τ = τy + Kγⁿ
(Hershel-Bulkley)
τ = τy + Kγ
(Bingham Plastic)
τ = Kγ
(Newtonian)
τy
Shear Rate γ

Rheology Results: Constants

- Bingham:
  - Yield Stress, τ_y ~ 70 to 90 Pa
  - Consistency Factor, K ~ 0.15 to 0.24 Pa-s

- Power Law:
  - Consistency Factor, K ~35 to 65 (Pa-s)^n
  - Flow Index, n ~ 0.13 to 0.20

Avert your eyes... it's math

- Power Law – Laminar Case:

$$h_f = 4f\frac{L}{D}\frac{\overline{V}^2}{2}$$

$$\Delta p = -\frac{2^{n+2}\left(\frac{3n+1}{n}\right)^n LK\overline{V}^n}{D^{n+1}}$$

$$f = \frac{2^{n+1}\left(\frac{3n+1}{n}\right)^n K}{\overline{V}^{2-n}D^n\rho}$$

$$Re_{PL} = 2^{3-n}\left(\frac{n}{3n+1}\right)^n\frac{\overline{V}^{2-n}D^n\rho}{K}$$

$$\mathrm{Re}_{PL,critical} = 2100\frac{(4n+2)(5n+3)}{3(3n+1)^2}$$

Hopefully you know someone with a spreadsheet…

TSP Headloss Pipe Diameter Changes.xlsm - Excel

	A	B	C	D	E	F	G	H	I	J
1			TSP to BLAF							
2										
3		Segment #	1	2	3	4	5	6	7	8
4		Segment Description	12" Suction	8" suction	8" Discharge	8" to 3" meter	3" meter	8" to 6"	6" to DCB3	8" to tank
5		Flow (gpm) =	180	180	180	180	180	180	180	180
6		Diameter (inch) =	12	8	8	8	3	8	6	8
7		Length (ft) =	5	0	2	78	7	103	408	437
8		Fitting K =	2.5	0.2	0.45	7.4		2	3.2	5.8
9		Specific Gravity =	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
10										
11		Consistency Factor, K (Pa.s^n) =	63.283	63.283	63.283	63.283	63.283	63.283	63.283	63.283
12		Flow Index, n =	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0.133
13										
14	Turbulent Flow	Critical Reynolds Number =	1828	1828	1828	1828	1828	1828	1828	1828
15		Reynolds Number =	2	10	10	10	339	10	28	10
16	Est by WRC (UK)		Laminar Flow	Laminar Flow	Laminar Flow	Laminar Flow	Laminar Flow	Laminar Flow	Laminar Flow	Laminar Flow
17		Velocity (m/s) =	0.156	0.350	0.350	0.350	2.490	0.350	0.623	0.350
18		Fittings Factor =	870.6	202.9	202.9	202.9	6.9	202.9	72.7	202.9
19										
20		D (m) =	0.30	0.20	0.20	0.20	0.08	0.20	0.15	0.20
21		Q (m^3/sec) =	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
22		L (m) =	2	0	1	24	2	31	124	133
23		Density (kg/m^3) =	1030	1030	1030	1030	1030	1030	1030	1030
24										
25		Wall Shear Stress (Pa) =	86.8	102.0	102.0	102.0	150.9	102.0	114.4	102.0
26		Wall Shear Rate (1/s) =	10.7	36.3	36.3	36.3	687.5	36.3	85.9	36.3
27										
28		Frictional Pressure (Pa) =	1736	0	1224	47745	16899	63048	373494	267495

Updated Hydraulic Calculations - TBPs

Parameter	Mulbargar
Flow (gpm)	135
Pressure (psi)	75
Motor size, calculated (hp)	20
Motor size, selected (hp)	40

- Had to make sure piping class was OK

Updated Hydraulic Calculations – Truck Loading Pumps

Parameter	Mulbargar
Flow (gpm)	500 - 1,000
Pressure (psi)	35 - 45
Motor size, calculated (hp)	60
Motor size, selected (hp)	125

Startup in Oct 2016

- Loaded 50 trucks during operational demonstration
- Pressure readings on the TBPs pumping to BLAF tanks up to 200psi
- Pumping from centrifuges to BLAF regularly since startup
- Over 9 million gallons pumped in 2017 through Nov.

Project Takeaways/Lessons Learned

- No mixing in storage tanks – only circulation
  - At least 4 turn-overs before sampling begins to get representative sample
- %TS decreases over time when stored – continued digestion?
- Great feedback from the haulers on the loadout station!

Summary of Best Practices for Design

- Sanks lays it out pretty well:
  1. Treat each sludge pumping application as a unique design problem
  2. Develop site specific design criteria based on detailed evaluation of the specific sludge characteristics.
- Establish range of operating conditions from clean water to worst case sludge scenario – especially for centrifugal pumps.
- Common sludges like raw, or digested, less than 5-6% TS – “textbook” or simplified approaches likely OK.
- If data exists for a “similar” sludge use it with caution.
- Hydraulic modeling softwares come with sludge correction/rheology models – apply with engineering judgement (do some homework on limitations/applicability).

When to do Rheology Testing?

- Pumping design
  - Especially for really thick or unusual sludge characteristics where data isn't available.
- Mixing designs
  - Confirm how much energy is needed and if the sludge will mix

Thanks to everyone involved!

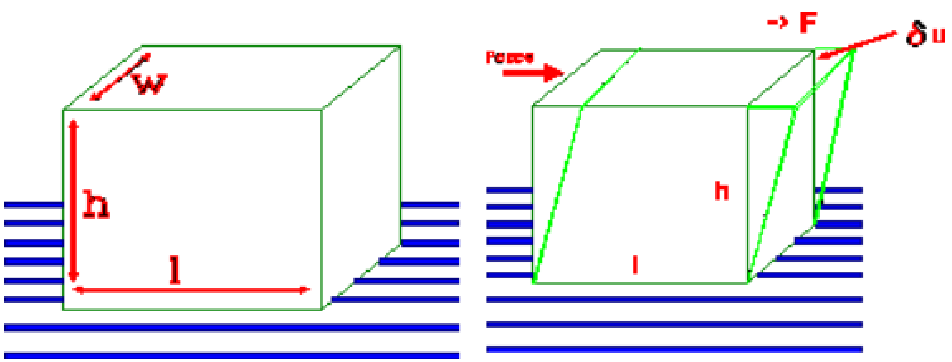
- Black and Veatch
  - Bob O'Bryan
  - Sierra McCreary
  - Tyler York
- City of Columbus
  - Troy Branson
  - Rick Kent
  - Everyone at SWWTP
- Brown and Caldwell
  - Dave Nitz
  - Dante Fiorino
  - Ravi Ravisangar (the man with the spreadsheet!)

Questions

Bullpen

More Rheology

- Shear Strain = δu/h
- Shear Stress = F/A = τ = N/m^2
- Shear Rate (Shear Strain Rate) = δ.Shear Strain/ δ.time = s^{-1}
- Viscosity (dynamic or absolute) = Shear Stress/Shear Rate = Ns/m^2 (Pa-s or Poise)
- Kinematic (divide by density) = m^2/s (Stokes)



Pump Types

- Centrifugal- Non-Clog
- Centrifugal- Recessed Impeller
- Screw-Centrifugal
- Progressive Cavity
- Rotary Lobe
- Piston Pumps
- Diaphragm