High Viscosity Foam Concentrates and Foam System Design

FIRE AUSTRALIA 2025, Sydney

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May 2025

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Our problems

1. The majority of foam systems installed – **world wide** – would not meet the design objectives of the foam system design codes.
2. Design codes set the design goals.
3. Design codes do **NOT** provide complete details on how to achieve these design goals.
4. Good engineering practice needs to be applied as well.

The major problems

1. Foam solutions are now more complex that previously and NFPA 11 is incorrect that they can be treated the same as water. We published a paper in 2023 to address this issue.
2. Foam tanks are incorrectly designed.
3. Foam concentrate flow modelling is currently not possible with any accuracy – for High viscosity concentrates. NFPA 11 pushes this issue onto the concentrate manufacturers, who are not qualified to deal with it.

Tank problems

1. There should only be ONE tank – no multiple tank systems. NFPA uses “The storage tank ….”. NFPA 11 Clause 4.3.2.3.1.2.
2. The tank must be elevated above the pump suction inlet height.   NFPA 11. NFPA 11 Clauses 4.3.2.3.1.5 & 4.3.2.3.2.5
3. There must be a pressure vacuum vent to control evapouration. NFPA 11 Clauses 4.3.2.3.2.4 & 4.3.2.3.1.5.
4. NFPA 11 does not tell you how to size the vent. This is a critical design issue. Total air flow losses + opening pressure < 3 kPa.

Foam concentrate flow modelling

1. F3 foams are mostly high viscosity products.
2. The fluid properties are extremely complex.
3. Fluid property data is not available or unreliable.
4. The tools to model foam concentrate flows are not available to foam system designers.
5. Concentrate property data provided by manufacturers is not adequate for engineering design.

Rheology Basics

- There are more to fluid properties than just **density** and **viscosity**.
- Foam standards only require these two properties to be reported, and often incorrectly.
- US products report viscosity with Brookfield #4 spindle at 30 and 60 rpm. These two data points have no value for designers. EN standards are better but still flawed.

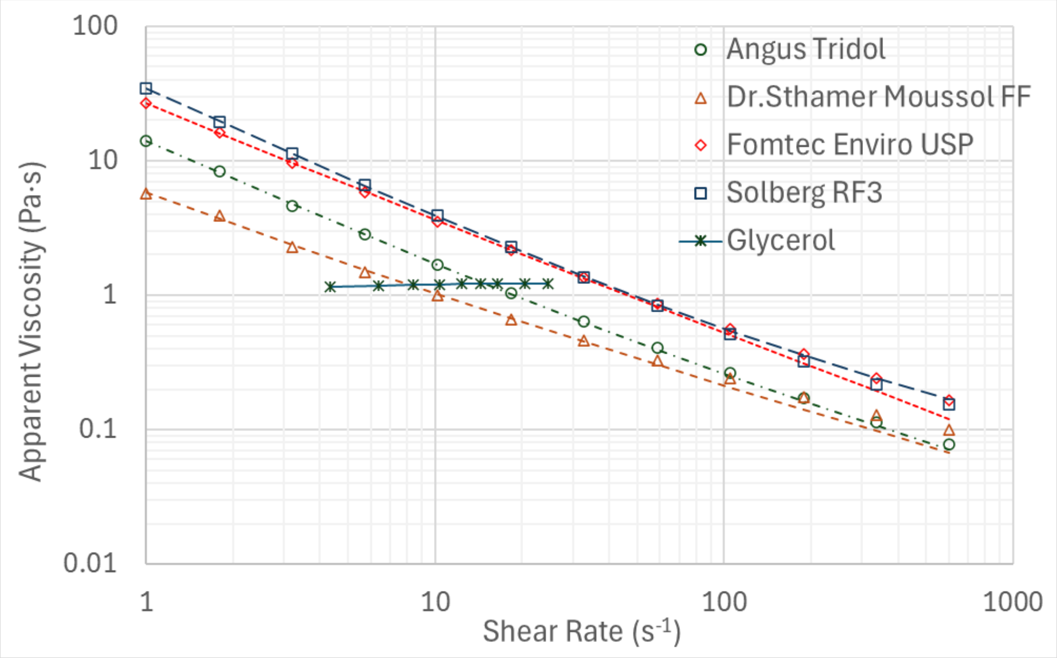
Rheology Basics

- Other important properties:
  - Yield Stress
  - Thixotropy

None of this information is readily available.

Rheology Basics

- Viscosity measurement – the **steady state** flow curve



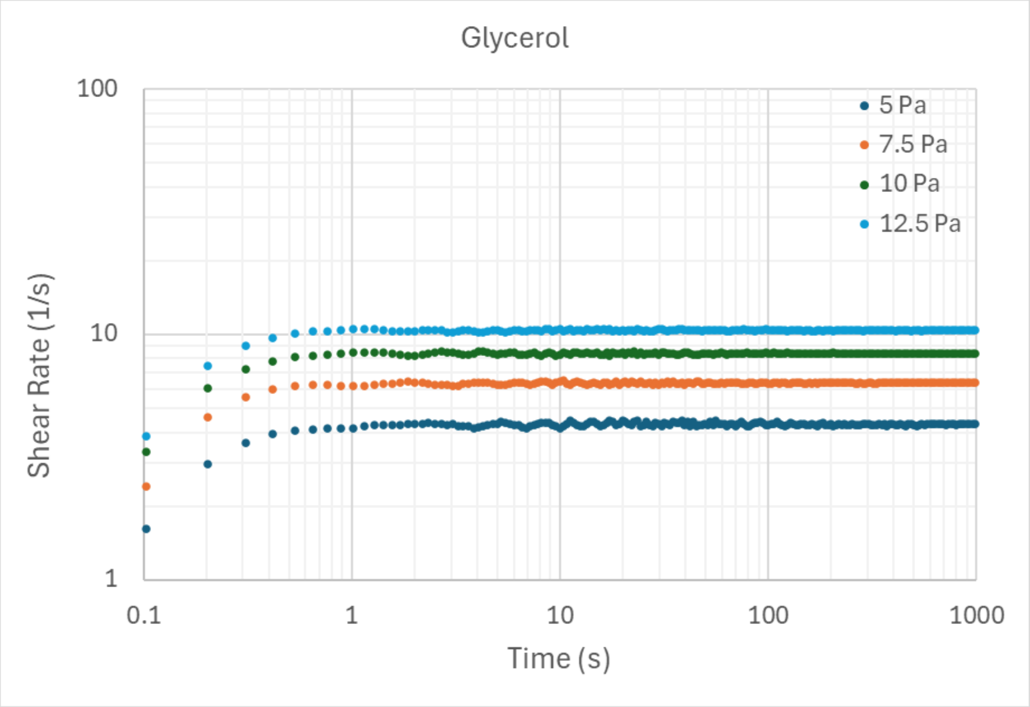
Shear thinning fluids
Non-Newtonian

A steady state flow curve does not exist for all foam concentrates

Glycerol - a viscous Newtonian fluid

Rheology Basics

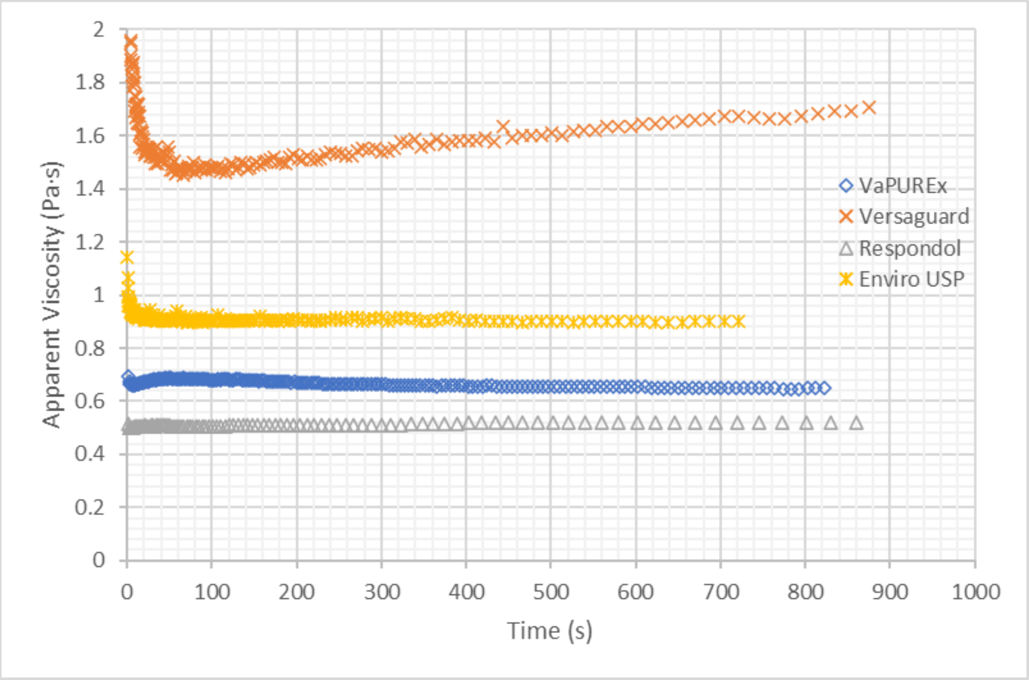
- Yield stress measurement and thixotropy – the creep test



Glycerol
steady state in 0.6 seconds
(machine response time)

Rheology Basics

- Viscosity measurement – the steady state flow curve

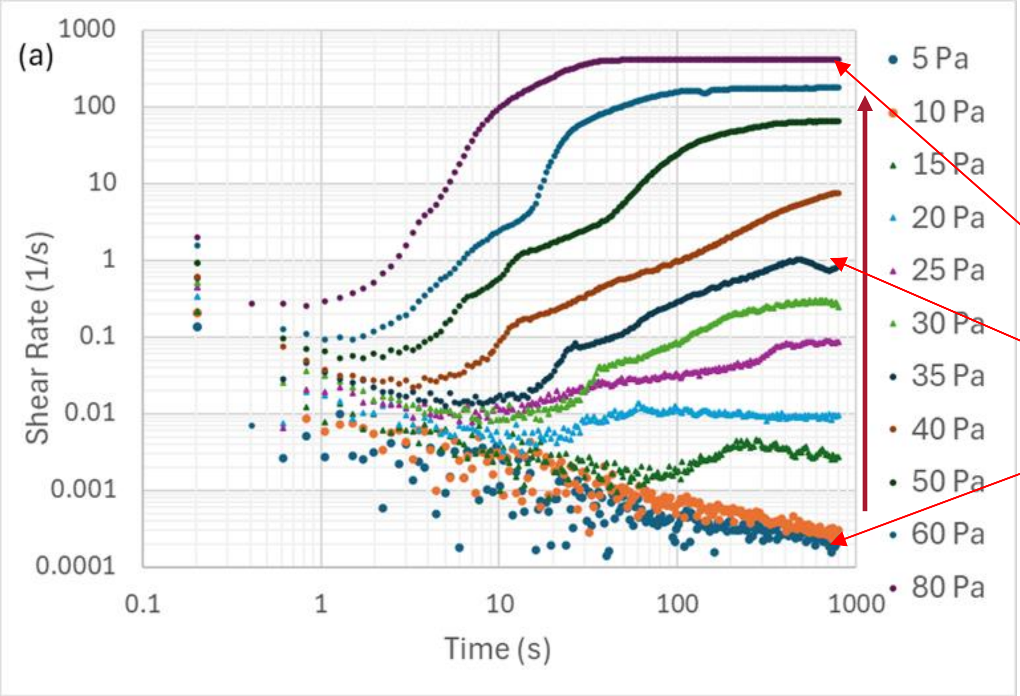


Single shear rate measurements

To check for steady state

Rheology Basics

- Yield stress measurement and thixotropy – the creep test



Creep test for RF3

Solid like behaviour below the yield stress

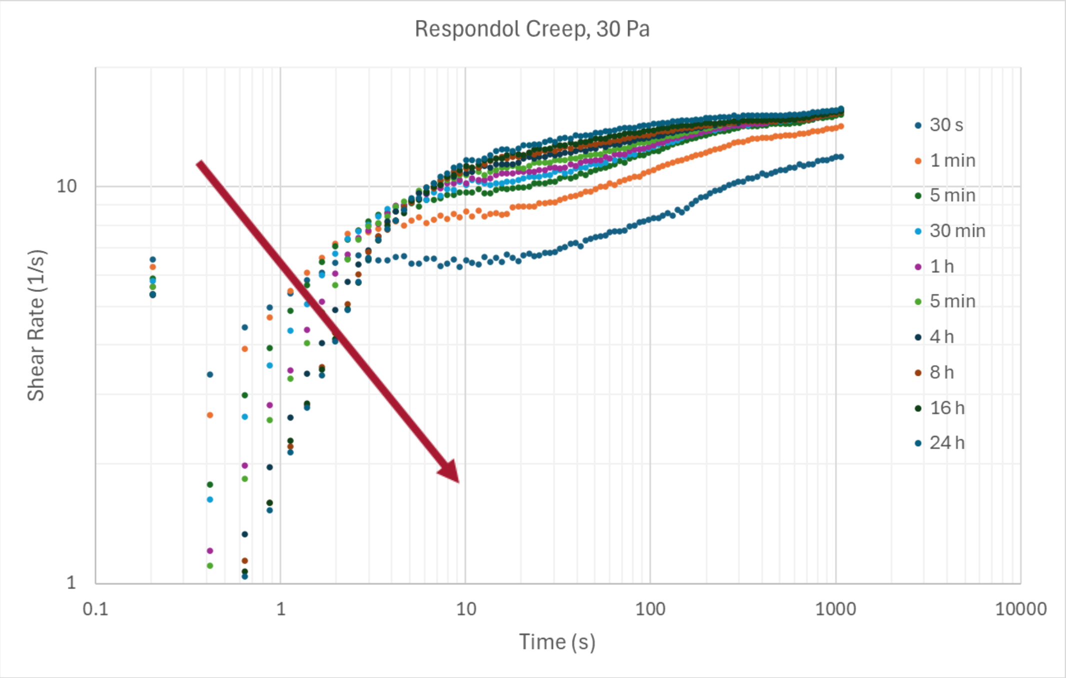
Yield Stress, 80 Pa

Yield Stress, 35 Pa

Yield Stress, 5 Pa

Rheology Basics

- Yield stress measurement and thixotropy – the creep test



Respondol Aging
No steady sate
No repeatable shear rate

The next challenge!

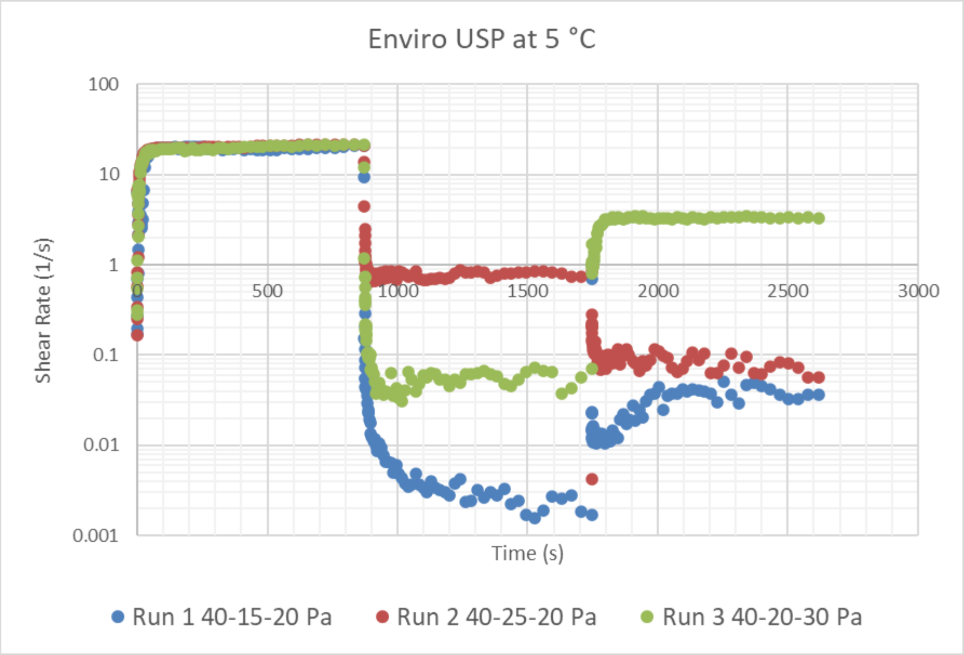
Rheology Basics

- Yield stress

Flow should stop when the applied stress is less than the yield stress.

This can be verified with a step creep test. Yield stress is 20 Pa.

Important for system design.



Steady State Flow

- Yield stress fluid – use the Herschel Bulkley fluid model

$$\tau = \tau_0 + k\dot{\gamma}^n$$

- Use the Darcy Weisbach equation
- Each fluid model can have its own Reynolds number
- Use the appropriate Reynolds number
- $Re_{HB} = \rho v^{(2-n)} D^n / (\tau_0/8).(D/v)^n + k.((3m+1)/(4m))^n.8^{(n-1)}$
- $m = n.k/(8v/D)^n/(\tau_0 + k(8v/D)^n)$

Madlener, K., Frey, B., & Ciezki, H. (2009). Generalized Reynolds number for non-Newtonian fluids. Progress in propulsion physics, 1, 237-250.

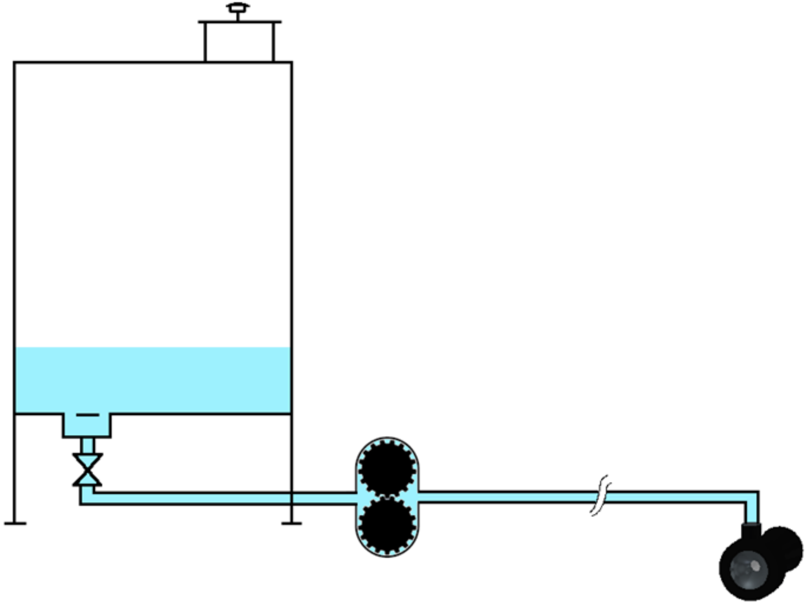
Foam Systems

Conventional pressure drop calculations have 2 important assumptions.

- The flow is **steady state**, with fluid properties constant in each pipe segment.
- Fluid properties change almost instantly with a change in flow conditions.

Neither of these assumptions are true for these foam concentrates.

Total friction loss = Air Inlet loss + suction pipe loss.

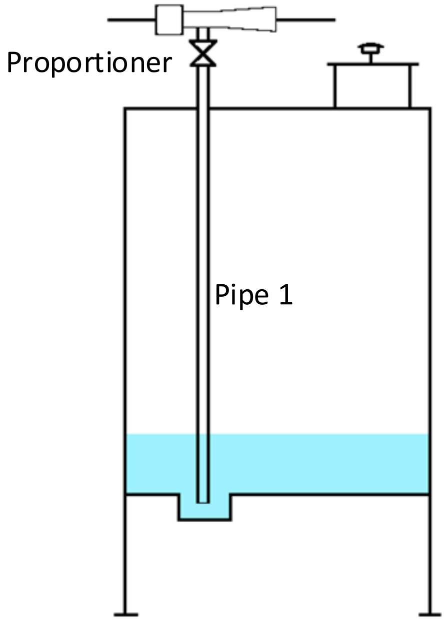


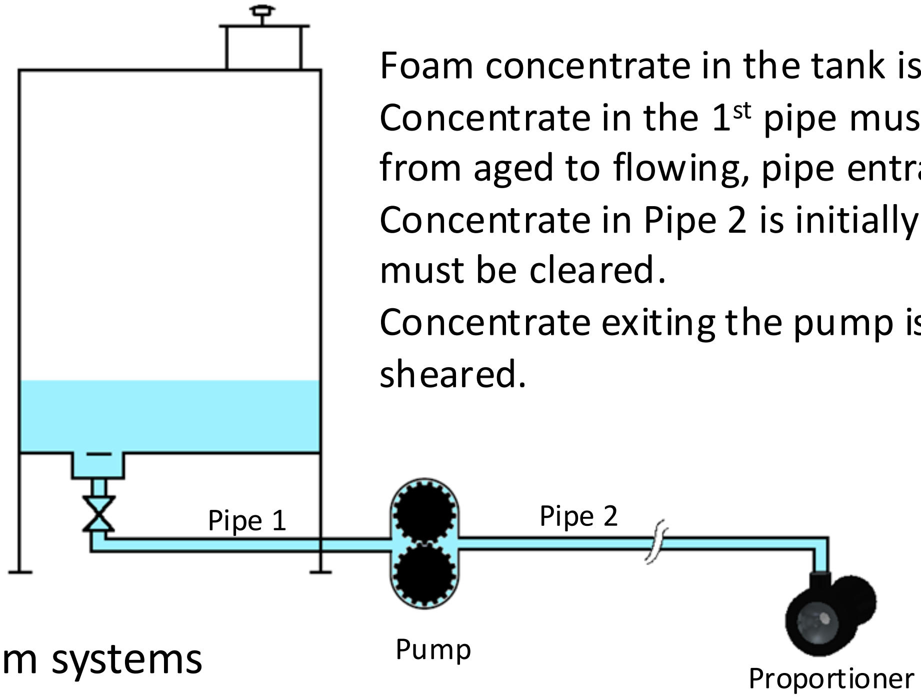
Foam Systems

Yield stress fluids result is some design problems.

- Tank sight glasses are inaccurate.
- Pressure signals will not transmit accurately through small tubes. Has implications for some pressure control valves and for mounting pressure gauges remotely.
- Pipes have a minimum pressure differential before flow starts, the pipeline start-up pressure. Long pipelines are not likely to be practical.
- The design case for pumping needs to be evaluated when the tank is almost empty to ensure that the operating time is achieved.
- Foam tanks must be elevated.
- Air bubbles in concentrate are not removed, or slow to rise. Impacts proportioning rate.

Foam Systems





Two typical foam systems

Foam concentrate in the tank is aged.
Concentrate in the 1st pipe must change from aged to flowing, pipe entrant flow.
Concentrate in Pipe 2 is initially aged & must be cleared.
Concentrate exiting the pump is fully sheared.

Foam System Design

There are 3 design states that the designer must deal with for the foam concentrate piping.

1. The suction pipe (Pipe 1) between the tank and the pump or venturi is a pipe entry flow problem, not a simple friction loss calculation.
2. The pump to proportioner pipe (Pipe 2) has an initial condition that it is full of aged foam concentrate. This is not dissimilar to the pipe entry problem. It is a flow start-up problem.
3. Once flow starts in Pipe 2, the flow can be reasonably treated as a steady state, non-Newtonian yield stress fluid flow.

Foam System Design

Estimation techniques

Start-up pressure $\Delta\mathrm{p} = 4\tau_0 L/D$ (pressure needed to achieve the yield stress along the pipe wall)

Herschel Bulkley steady state

Pipe entry flow model (Herschel Bulkley pipe entry)

Numerical solutions

The height of the foam tank outlet should provide a minimum of the startup pressure above the pump inlet. OR MORE.

Foam System Design

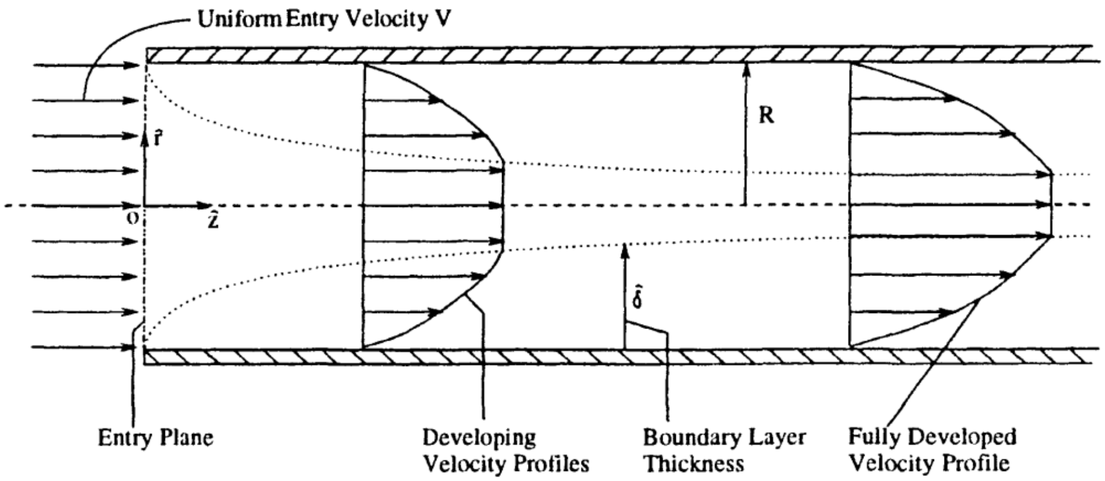
Pipe Entry Flow

Aged, unyielded concentrate enters the pipe and shear thins to steady state flow.

Distance for steady state flow to develop is the pipe entry length.

Higher friction loss than steady state flow.

This can be calculated for each pipe and each fluid, but ignores fluid thixotropy. It will underestimate the entry length and the friction losses.

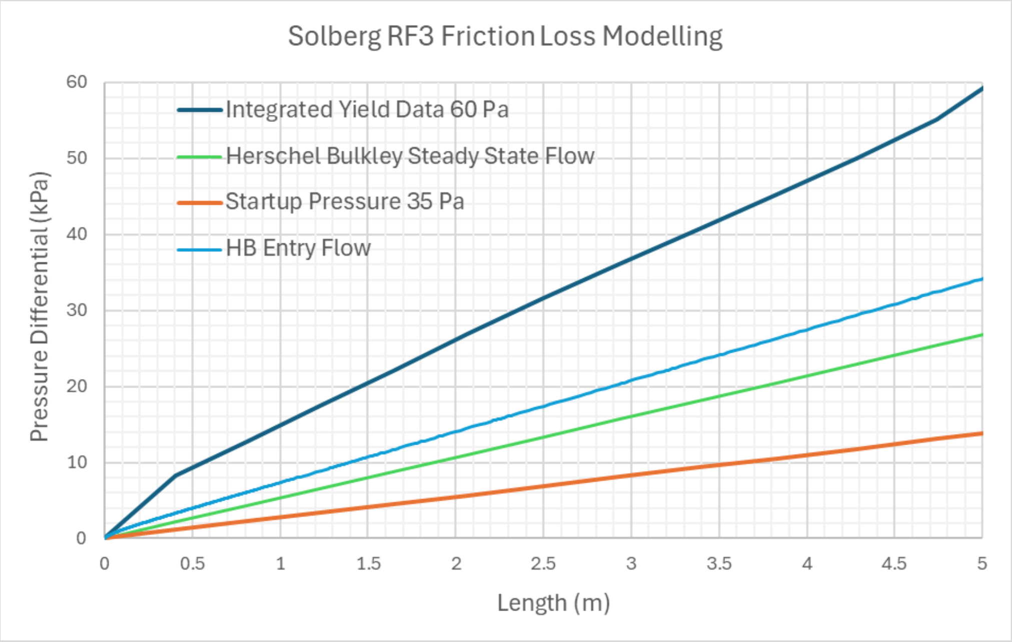


SUCTION PIPE VELOCITIES <0.5 m/s are recommended

GUPTA, R. and Y. ZHAO Laminar Entry Flow of Herschel-Bulkley Fluids in a Circular Pipe.(2000). <u>Advances in Fluid Mechanics III: Proceedings of the 3rd International Conference on Advances in Fluid Mechanics AFM 2000: Montreal, Canada, 24-26 May.</u>

Foam System Design

Pipe Entry Flow



Our goal is to find a computationally simple estimator for design of piping.

- Pipeline start-up pressure underestimates pressure losses
- Steady state Herschel Bulkley calculations underestimate pressure losses
- The pipe entry flow model underestimates pressure losses
- Integrating of experimental data is not simple

Conclusions

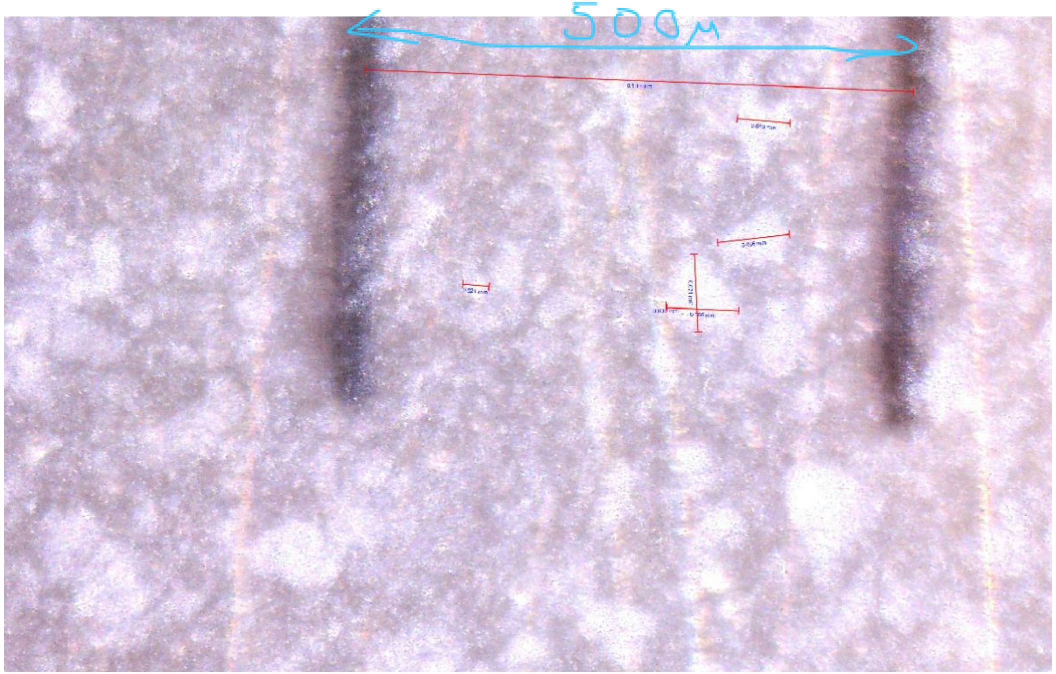
- Foam concentrates are very complex fluids. They are thixotropic elastoviscoplastic fluids that age/gel when stored.
- Fire system design codes need to be updated to include the changes occurring due to FfreeF foam developments. More complex fluids.
- It is not reasonable to expect Foam Concentrate manufacturers to provide advice on system design.
- Designers need much better rheological data than currently provided.
- The tools do NOT currently exist to design foam systems correctly.

Questions?

- Our thanks to Ted Schaefer for leading the change to fluorine free foams.

Rheology Basics

- Two phase foam concentrate – Angus Respondol

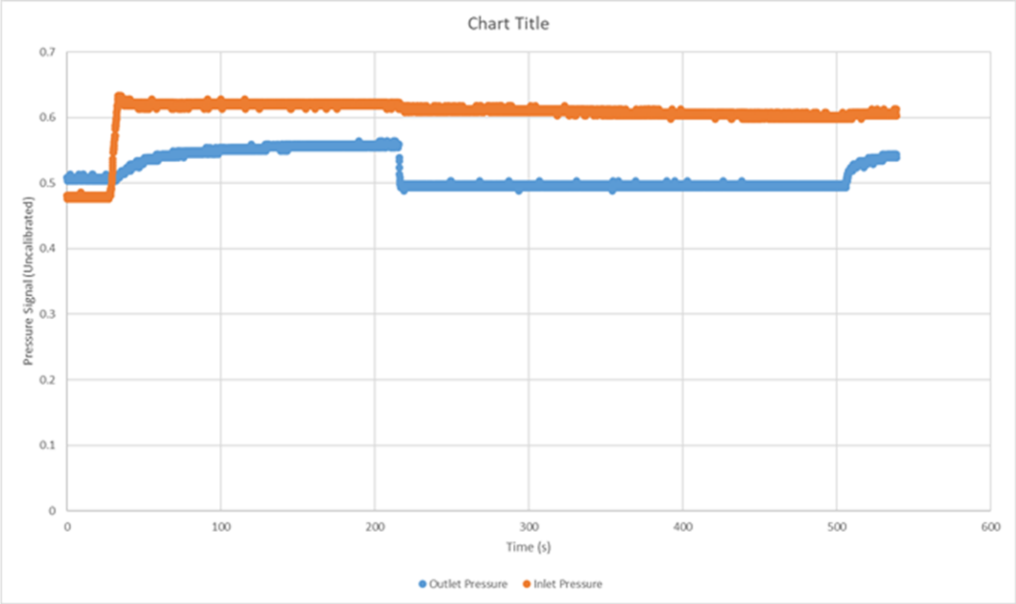


Solid particles suspended in fluid

Particle size approx. 100 µ
Non-Brownian

Rheology Basics

Slow flow behaviour



Pressure signal delay in 3/8” OD tube with Solberg RF3 foam concentrate

100 kPa pressure signal, above yield stress

Selected References

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