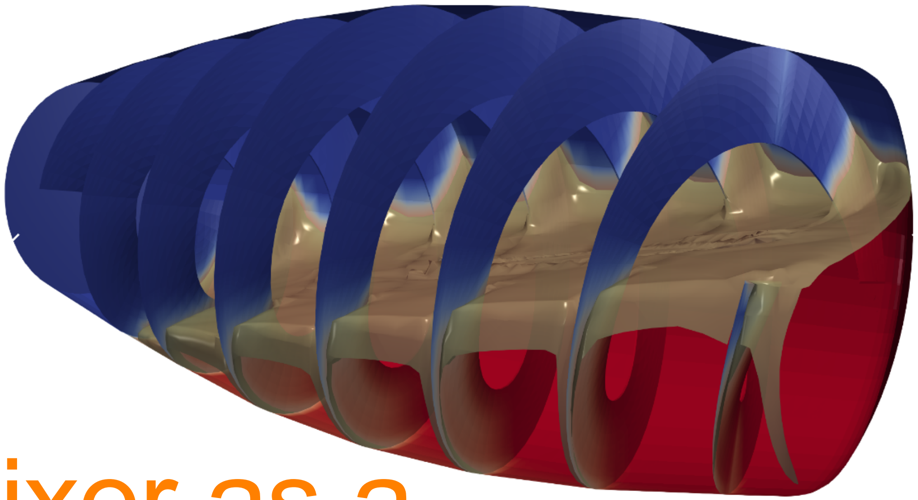


Concrete truck mixer as a rheometer *- mæling á sigmáli steypu með tromlu steypubíls*

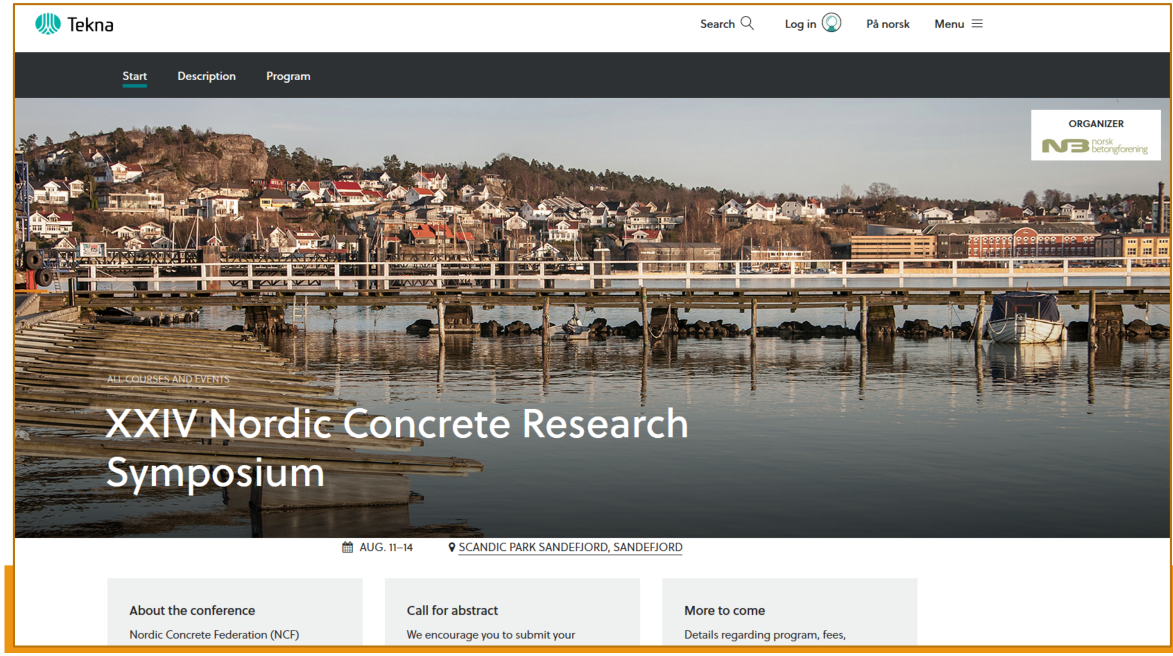
Dr. Jon E. Wallevik, ICI Rheocenter
Prof. Olafur H. Wallevik, Reykjavik University

Innovation Center Iceland

Nordic Concrete Research Symposium Sandefjord Aug (11)12th-14th 2020

Get to together and exchange experience and ideas within our Nordic community

Abstracts will be accepted until February 23rd



www.nordicconcrete.net

Gísli Guðmundsson
gislig@nmi.is

Bingham mod

Two rheological parameters are commonly used in descripting the rheological behavior of fresh conc

Yield stress τ_0 ("*tau*")

Plastic viscosity μ ("*mu*")

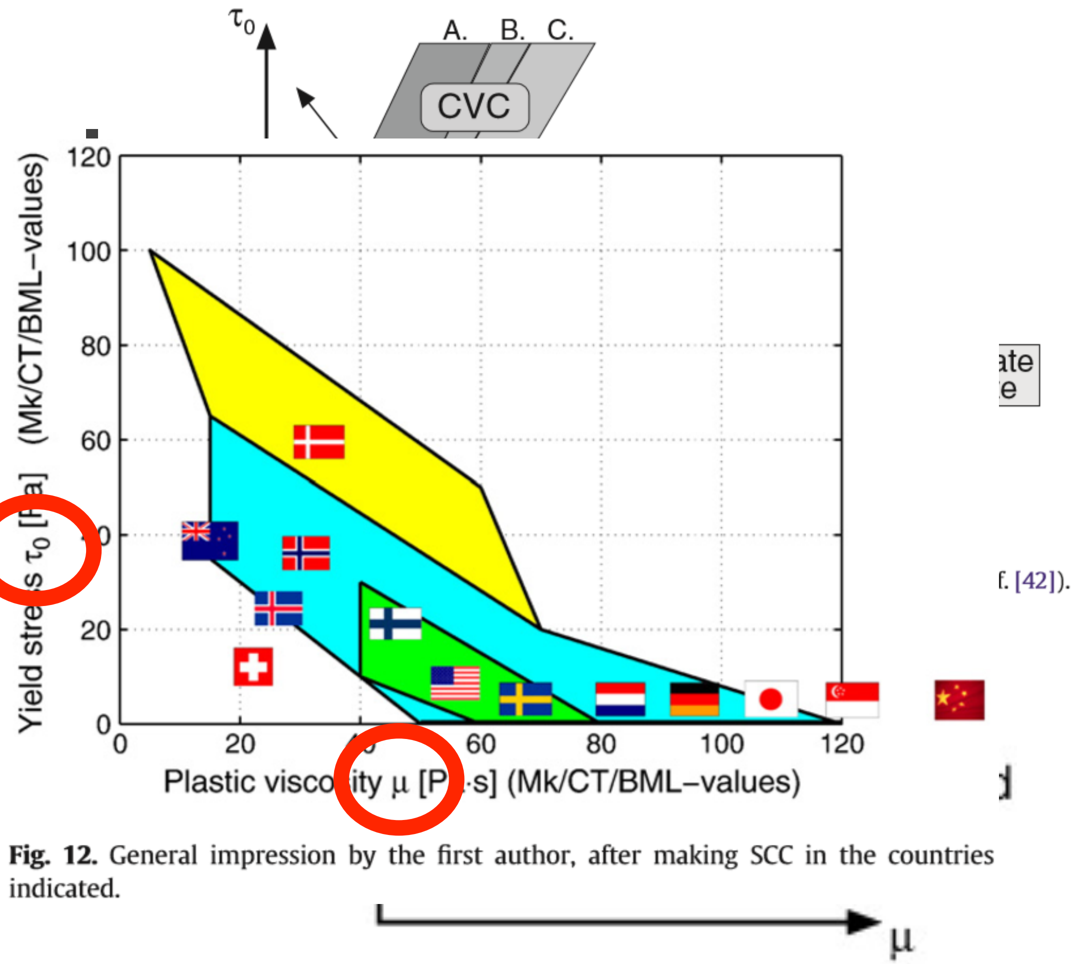
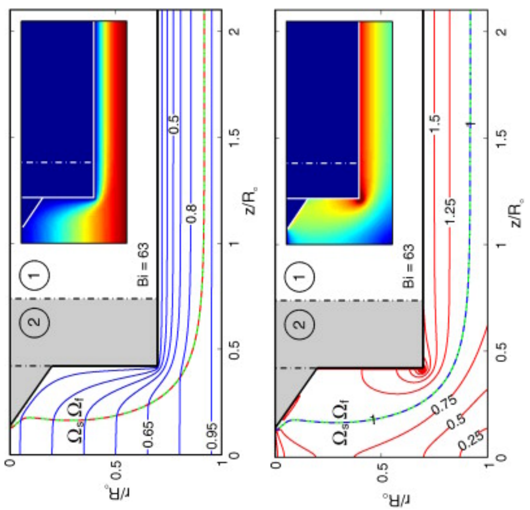
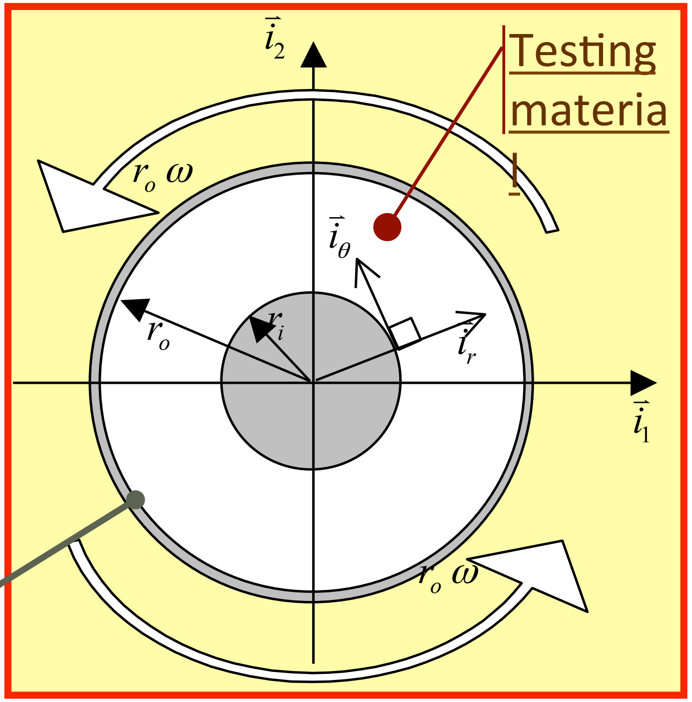


Fig. 12. General impression by the first author, after making SCC in the countries indicated.

Rheology as a tool in concrete science: The use of rheographs and workability boxes, OH Wallevik, JE Wallevik, Cement and concrete research 41 (12), 1279-1288

Measurement of τ_0 and μ

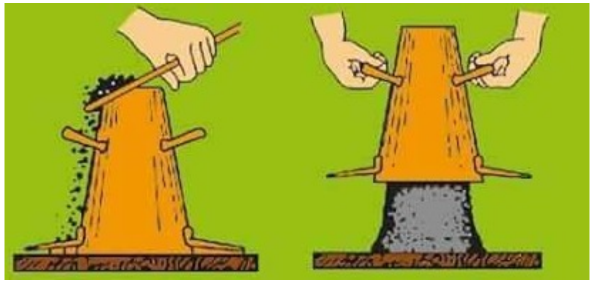


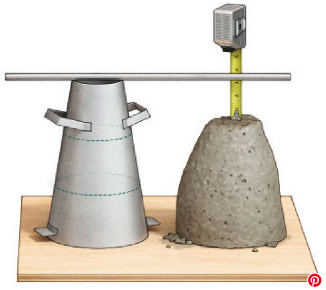


The container which the cement based material is pored in to

The inner cylinder is stationary and registers the applied torque from the testing material

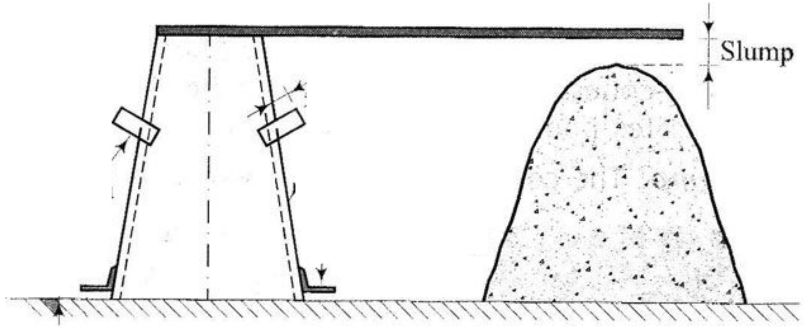
Slump (sigmál)





$$\tau_0$$

yield stress



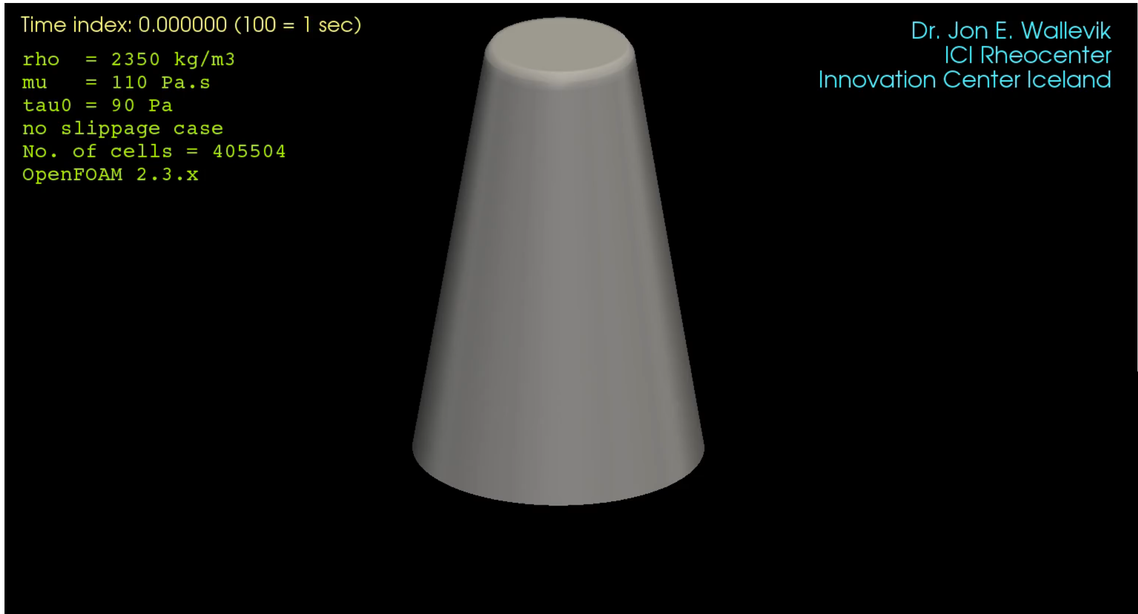
τ_0

Low yield stress
= high slump
(self leveling /
compacting
concrete)

$$\tau_0$$

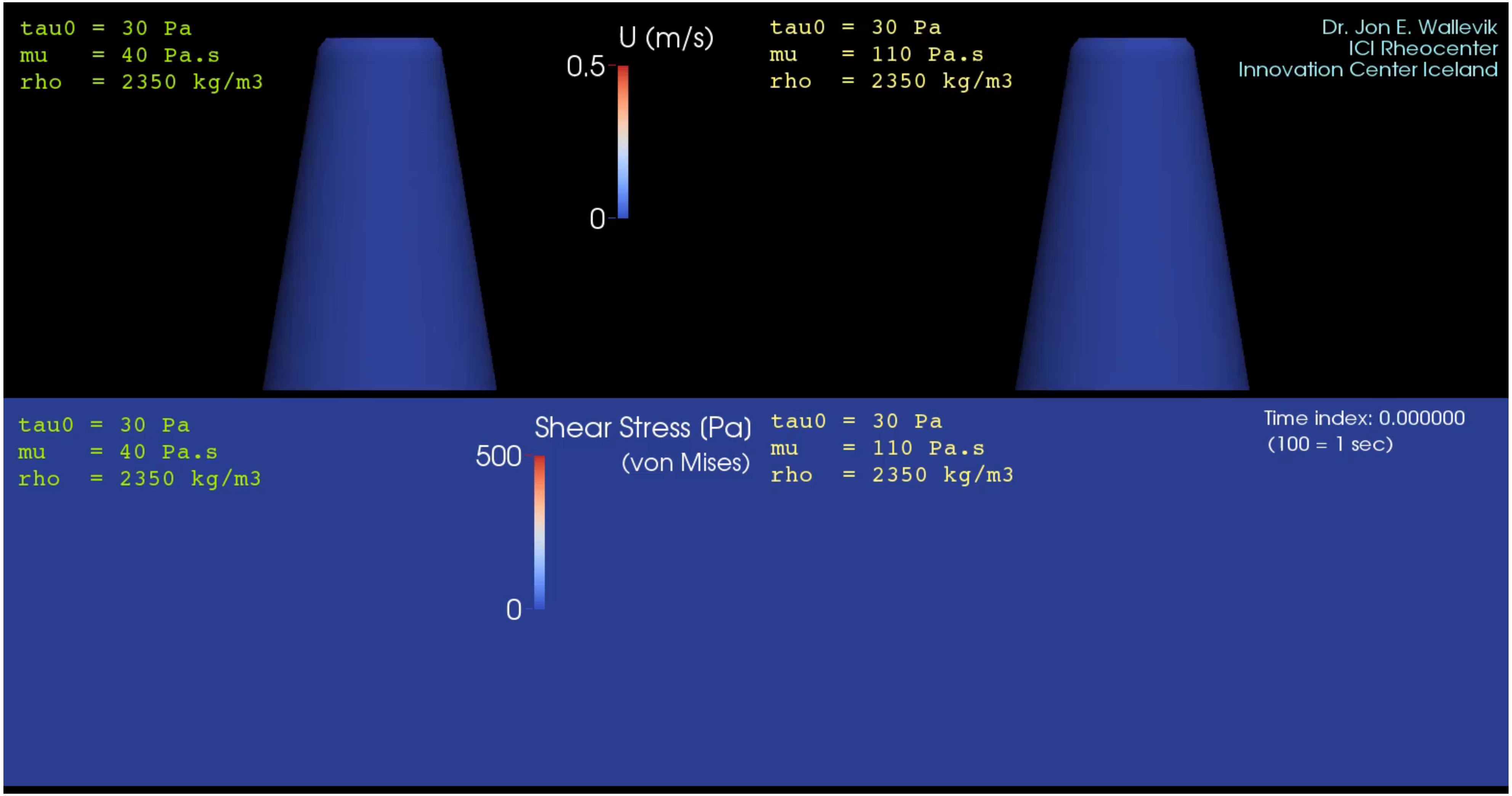
Hi yield stress
= small slump
(stiff concrete)

Plastic viscosity μ

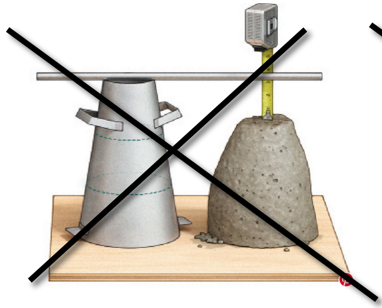


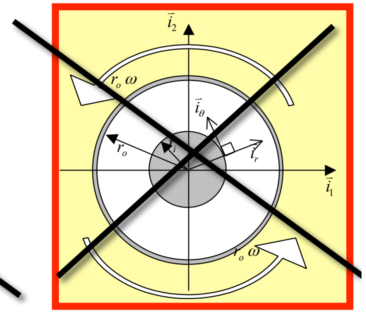
μ Low plastic viscosity (fast fluid flow)

μ High plastic viscosity (slow fluid flow)


tau0 = 30 Pa
mu = 40 Pa.s
rho = 2350 kg/m3
U (m/s)
0.5
0
tau0 = 30 Pa
mu = 110 Pa.s
rho = 2350 kg/m3
Dr. Jon E. Wallevik
ICI Rheocenter
Innovation Center Iceland
tau0 = 30 Pa
mu = 40 Pa.s
rho = 2350 kg/m3
Shear Stress (Pa)
(von Mises)
500
0
tau0 = 30 Pa
mu = 110 Pa.s
rho = 2350 kg/m3
Time index: 0.000000
(100 = 1 sec)

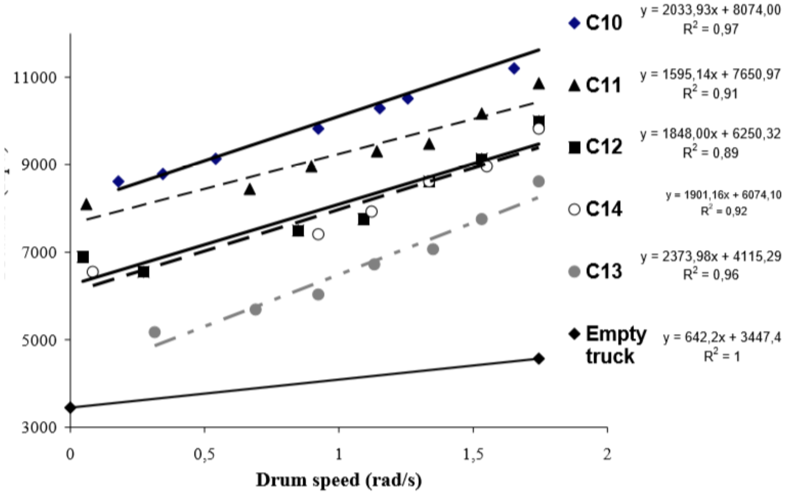
Measurement of τ_0 and μ





NISTIR 7333

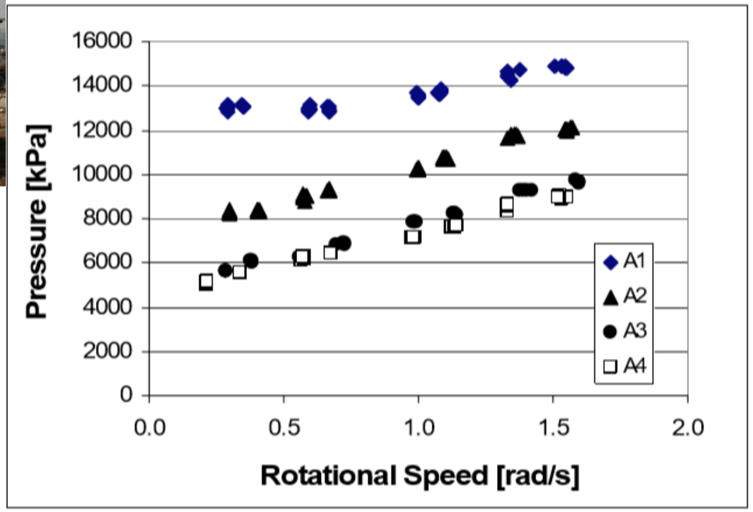
Figure 2: View of the truck used, the slump indicator, and the interior of the drum

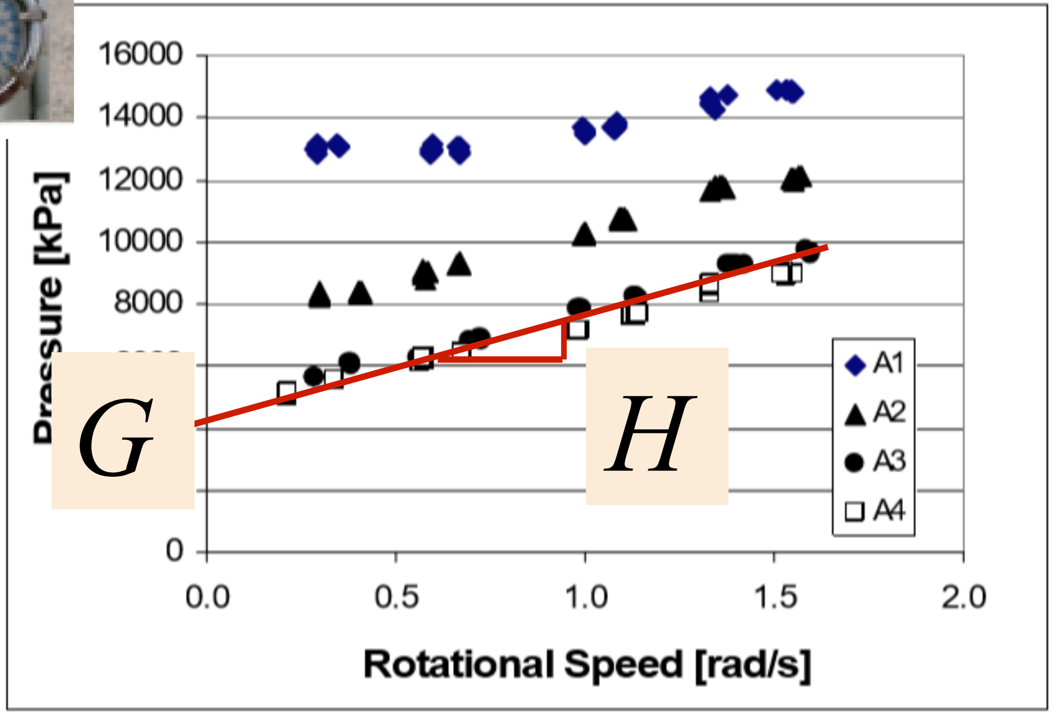


- monitor rotation speed
- power is recorded

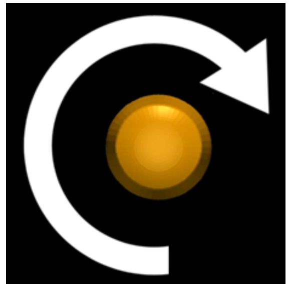
NISTIR 7447

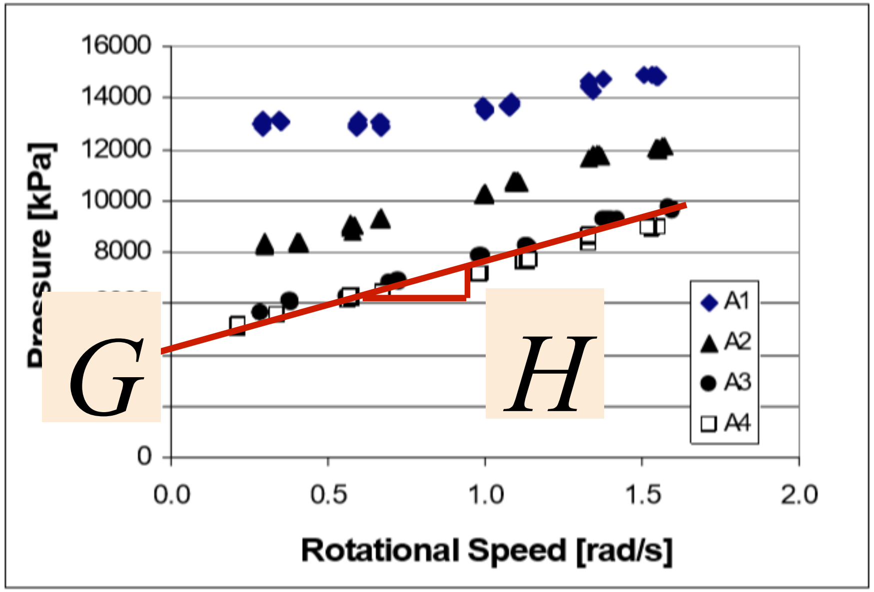
Top Row: left to right: Richard Arnold, Chris Doss, Ken Floyd, Max Peltz, Joe Grein, Scott Rogers, Steve Verdino, Roy Cooley
Bottom Row: left to right: Ed Dunstan, Chiara Ferraris, Mike Topputo, Terry Miller, Dave Westcott



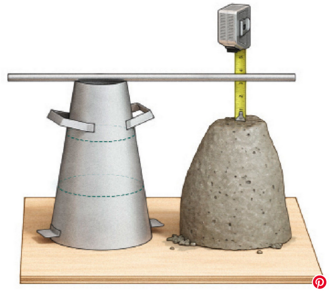


16000
14000
12000
10000
8000
0
0.0
0.5
1.0
1.5
2.0
Pressure [kPa]
Rotational Speed [rad/s]
A1
A2
A3
A4
G
H

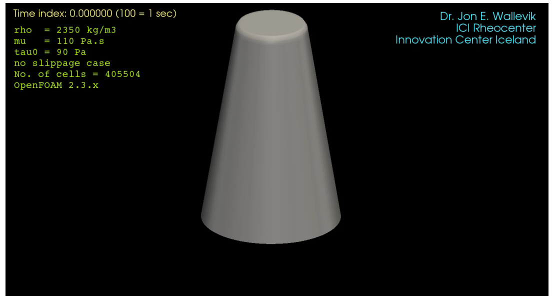


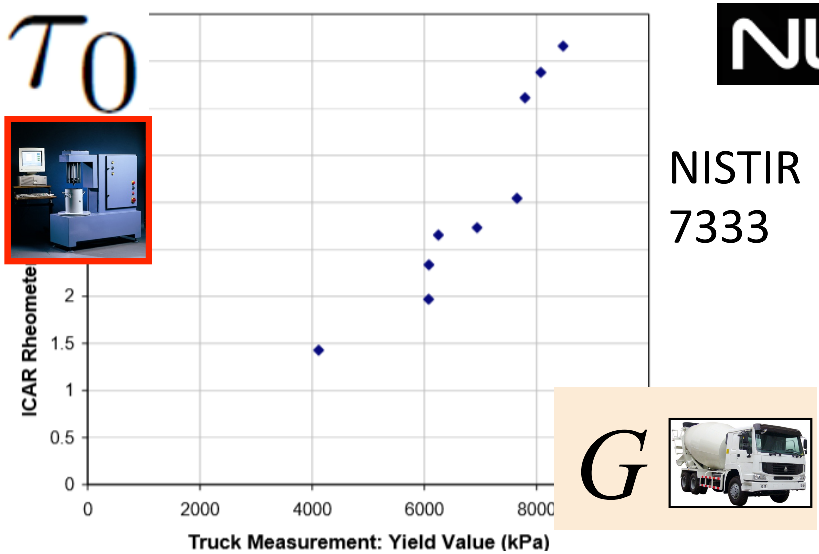


$$G = Q_1 \tau_0$$



$$H = Q_2 \mu$$





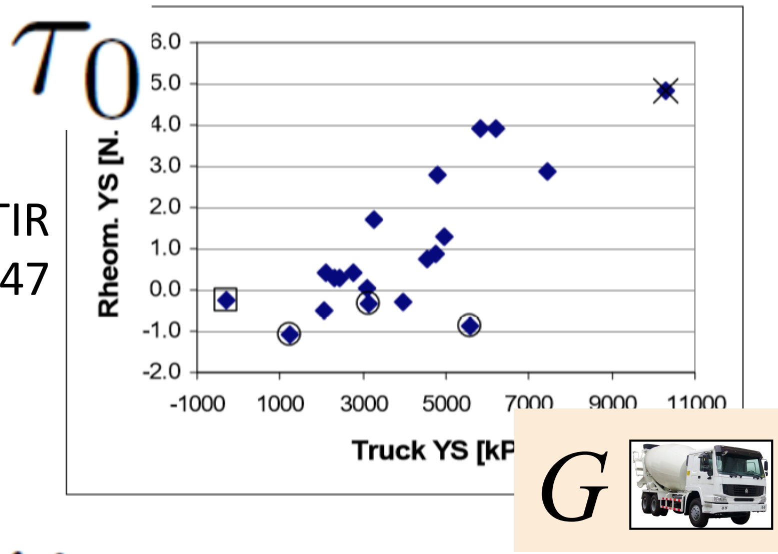
NISTIR
7333

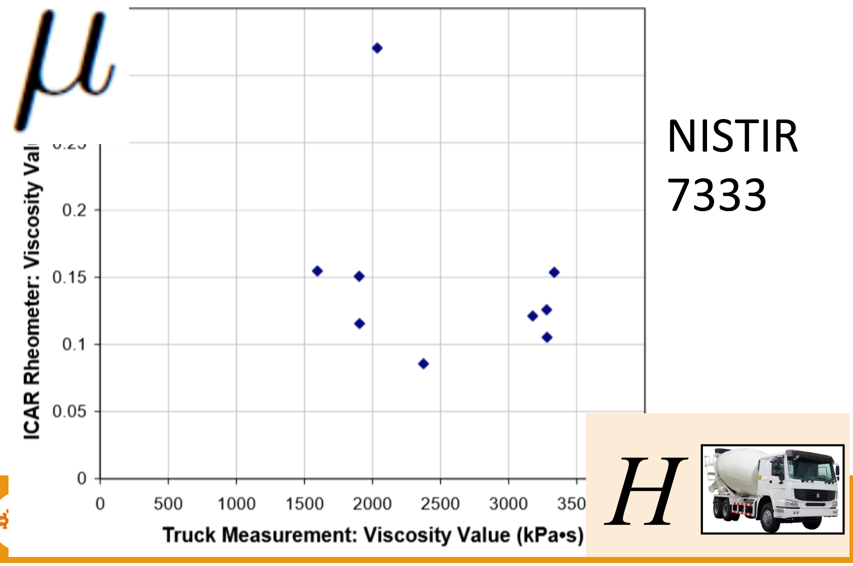
$$H = Q_2\,\mu$$

$$G = Q_1\,\tau_0$$

?

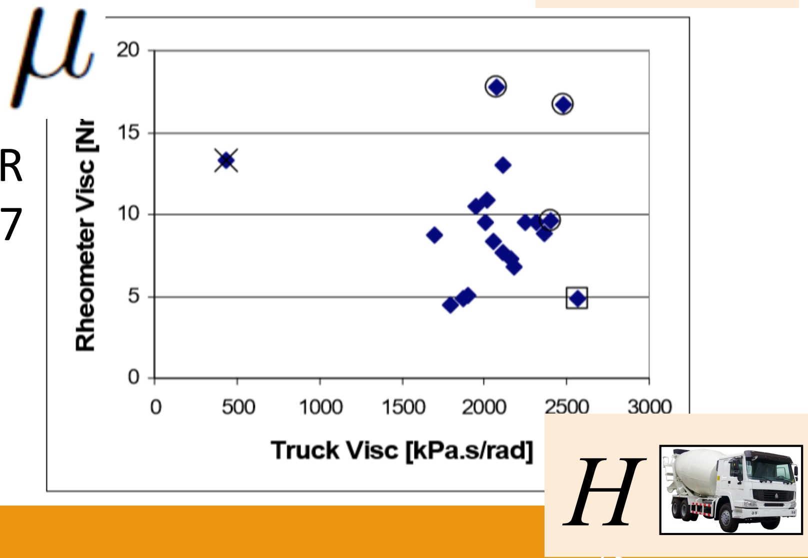
NISTIR
7447





NISTIR
7333

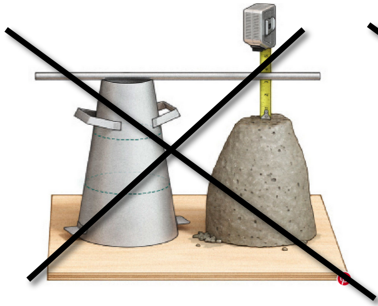
NISTIR
7447

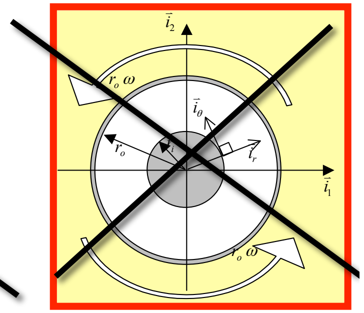


For real experiments: experimental errors

- C.F. Ferraris, R. Cooley, J. Grein, M. Peltz, M. Topputo, S. Verdino, Feasibility of Using a Concrete Mixing Truck as a Rheometer (Orlando, Florida), NISTIR 7447, September 2007:
  - Mechanical friction between the drum and the rest of the truck,
    - *from gearing box, bearing balls, carrying rollers and so forth*
  - incorrect truck sampling
  - insufficient mixing time after addition of chemical admixtures
  - …

Measurement of τ_0 and μ

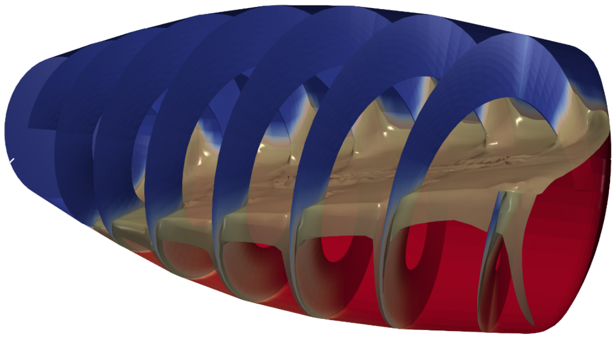




The current work is done to investigate the feasibility in using the truck mixer as a rheological device

The power is calculated in kilowatts [kW]

- can be related to the hydraulic pressure to turn the drum i.e. slump meter



Icelandic High Performance Computing (IHPC)
- http://ihpc.is

UNIVERSITY OF ICELAND

Garðar

Garpur (active)

Powered by CentOS

OpenFOAM
The OpenFOAM Foundation

KARRENA 9/5

Drum volume of 15.7 m^3

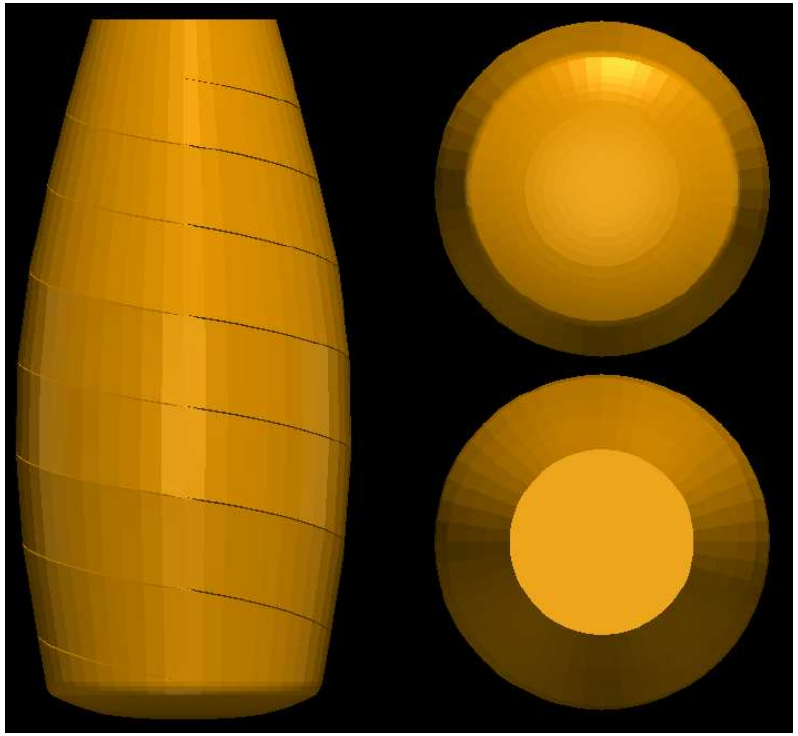
Max rated drum capacity is 9 m^3

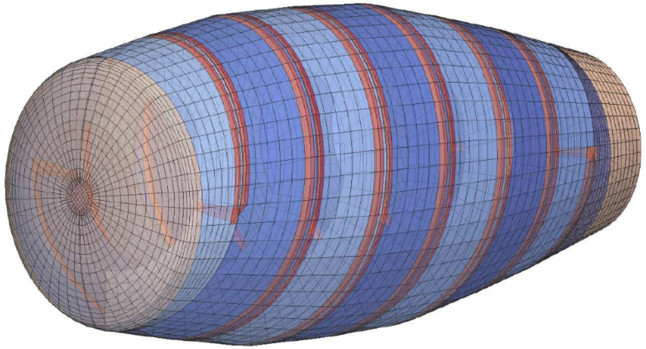
Drum speed is between 0 and 0.23 rps

- i.e. from 0 and 14 rpm

Inclination of the drum relative to the horizontal, is 11 degrees

Meshing of the drum was made with OpenFOAM utility called blockMesh



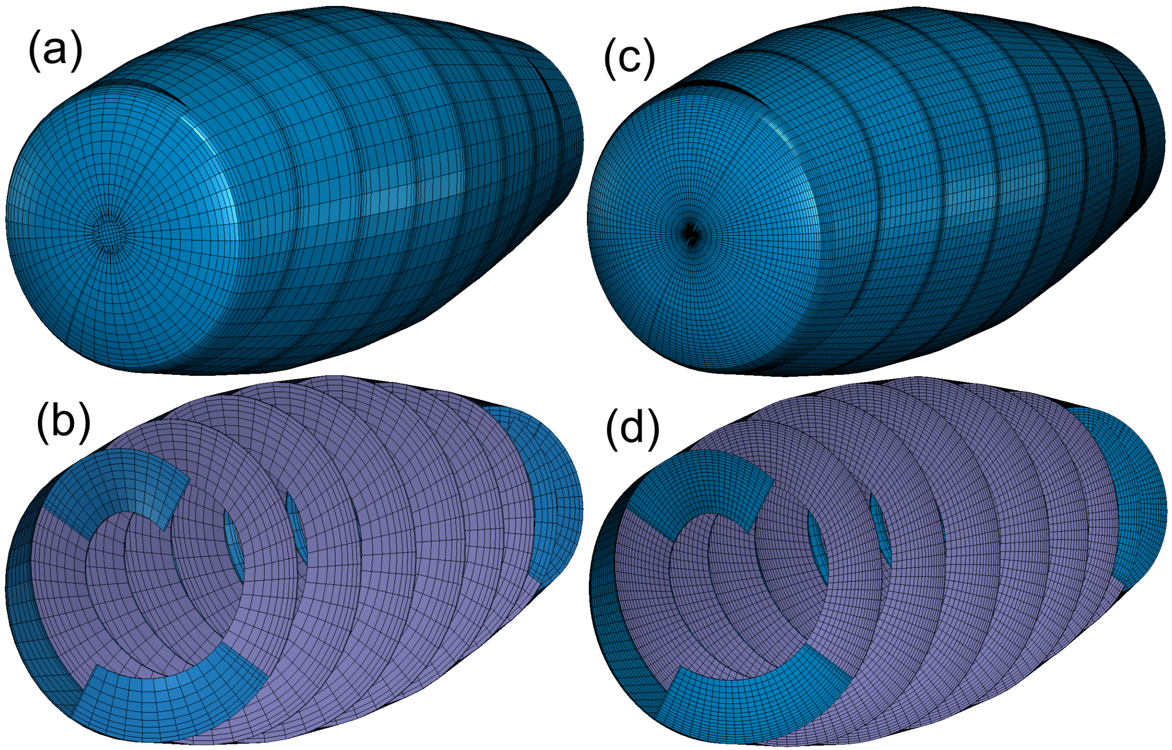


Trying to get drawings of the drum on the inside was not successful. Therefore a direct measurements of the drum was necessary!

This was done at the ready-mix plant Steypustöðin ehf in Reykjavik with one of their truck mixer

STEYPUSTÖÐIN

Mesh independence analysis



About 60,000 cells (to the left) & about 400,000 cells (to the right)

Cement and Concrete Research 127 (2020) 105930

Contents lists available at ScienceDirect

Cement and Concrete Research

journal homepage: www.elsevier.com/locate/cemconres

Concrete mixing truck as a rheometer

Jon Elvar Wallevik[a,*], Olafur Haralds Wallevik[a,b]

[a] ICI Rheocenter, Innovation Center Iceland, Arleynir 2, Reykjavik IS-112, Iceland
[b] Reykjavik University, Menntavegi 1, Reykjavik IS-102, Iceland

ARTICLE INFO

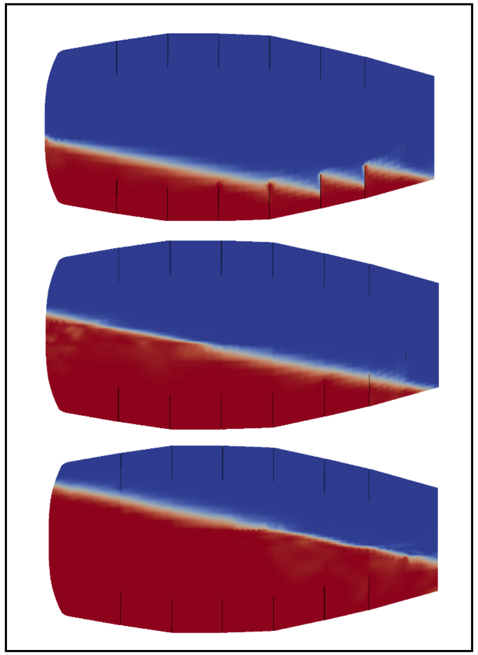
Keywords:
Truck mixer
Rheology
Bingham model
Fresh concrete
CFD

ABSTRACT

An increasing interest has emerged in correlating the output of the concrete mixing truck to values obtained by rotational rheometers. The output of the former has usually been the hydraulic pressure needed to turn the drum. In such research, experimental errors can be higher than usual, which makes it harder to obtain confident relationships. To better understand the physical characteristics of the truck's rheological values, the above analysis is made by a series of computer simulations (i.e. with CFD). From this, it is evident that the slope H of the truck's pressure values depends both on the plastic viscosity μ as well as on the yield stress τ_0. However, for the intercept G of the truck's values, it is mostly dependent on the yield stress τ_0. In addition to this, both values H and G depend on volume of concrete in the truck as well as on density.

Test setup

The power analysis is done as a function of drum charge volume 2.5 m^3, 5.4 m^3 and 8.2 m^3



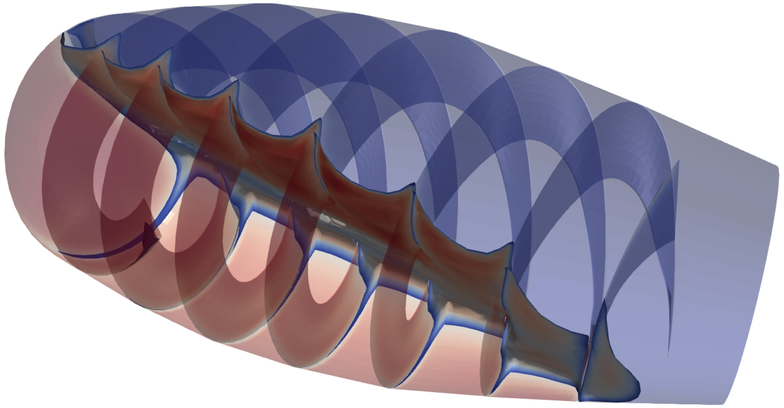
At different drum rotational speed

f = 0.03, 0.07, 0.11, 015, 019 and 0.23 rps

Test setup (cont.)

Yield stress and plastic viscosity,…

- $\tau_0 = 0$ Pa & $\mu = 25$ Pa·s
- $\tau_0 = 150$ Pa & $\mu = 25$ Pa·s
- $\tau_0 = 300$ Pa & $\mu = 25$ Pa·s
- $\tau_0 = 0$ Pa & $\mu = 75$ Pa·s
- $\tau_0 = 150$ Pa & $\mu = 75$ Pa·s
- $\tau_0 = 300$ Pa & $\mu = 75$ Pa·s
- $\tau_0 = 0$ Pa & $\mu = 125$ Pa·s
- $\tau_0 = 150$ Pa & $\mu = 125$ Pa·s
- $\tau_0 = 300$ Pa & $\mu = 125$ Pa·s

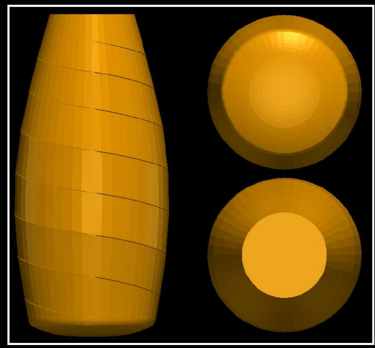


More than 150,000 CPU hours on the IHPC

Rotation of the drum

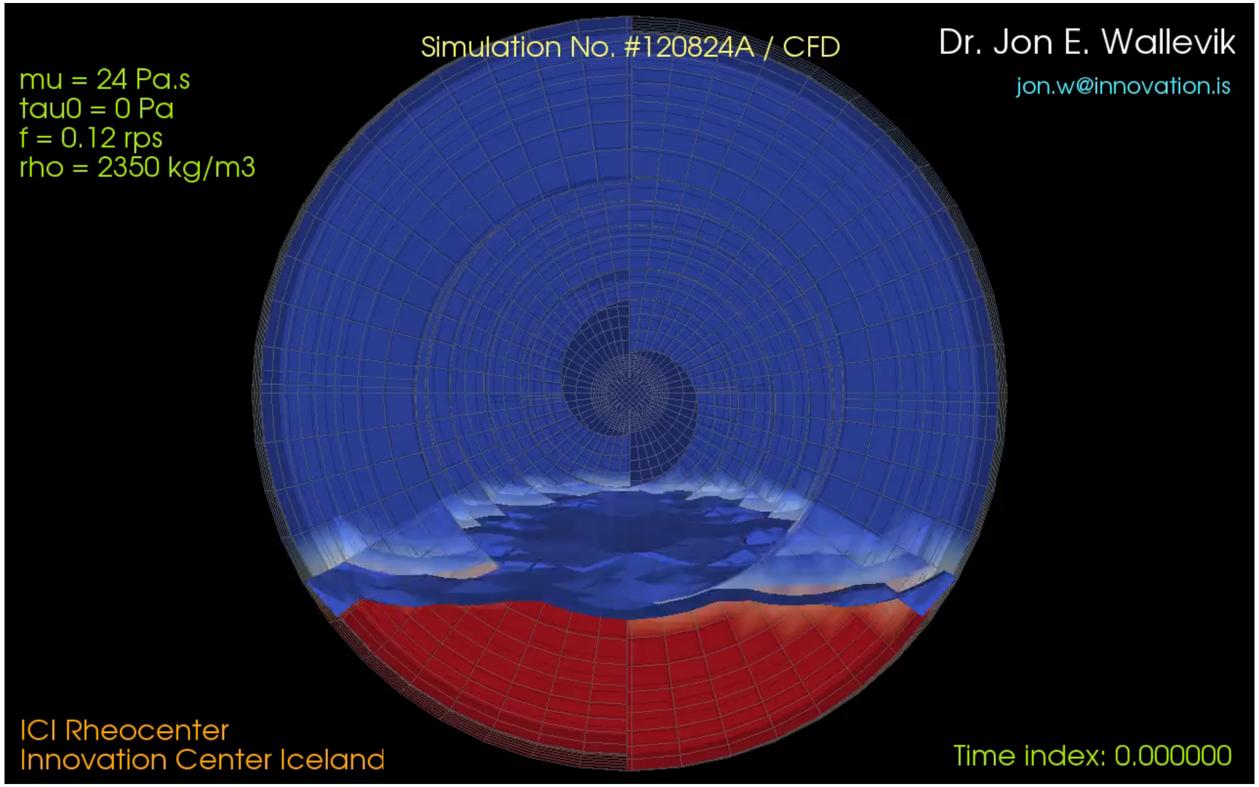
Gravity rotation

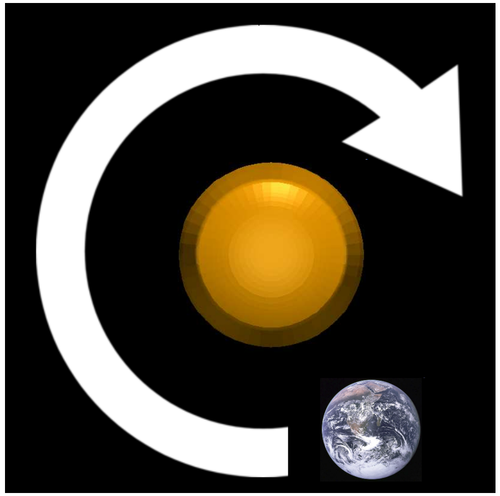
- Instead of physically rotate the computational mesh, the gravity-field is rotated
- The system represents no longer an inertial reference frame
  - **Coriolis force and the centrifugal force have to be included**



Instead of rotating the drum on a stationary Earth, the drum is stationary and the Earth rotates around it

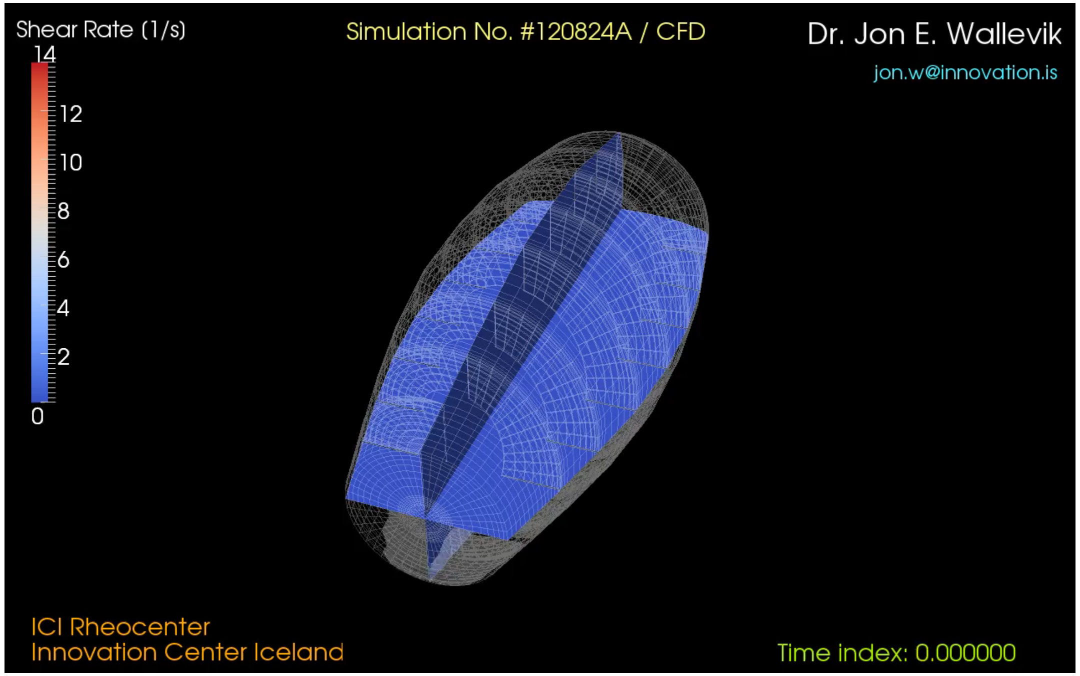
Single Rotating Reference Frame (SRF) Modeling (i.e. here by gravity rotation)

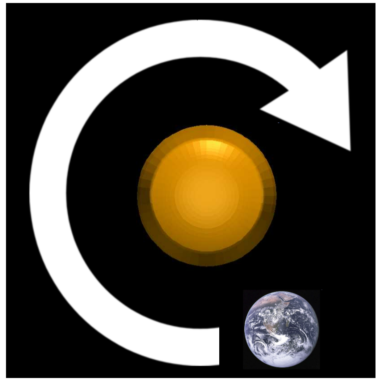


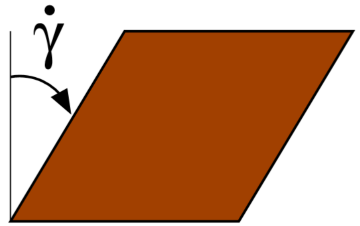


Single Rotating Reference Frame (SRF) Modeling (i.e. here by gravity rotation)

$$\dot{\gamma} = \sqrt{2\,\dot{\varepsilon}:\dot{\varepsilon}}$$



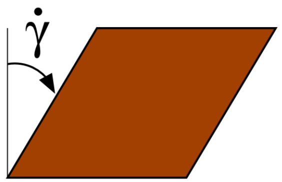




$$\left(\frac{\partial \rho \mathbf{U}}{\partial t}\right) + \nabla\cdot(\rho\,\mathbf{U}\mathbf{U}) + \mathbf{F}_{\mathrm{cor}} + \mathbf{F}_{\mathrm{cen}} = -\nabla p + \nabla\cdot\mathbf{T} + \rho\,\mathbf{g} + \mathbf{F}_s.$$

$$\mathbf{T} = 2\,\eta\,\dot{\boldsymbol{\varepsilon}}$$

$$\eta = \mu + \tau_0/\dot{\gamma}$$



$$\dot{\gamma} = \sqrt{2\,\dot{\boldsymbol{\varepsilon}} : \dot{\boldsymbol{\varepsilon}}}$$

$$\dot{\boldsymbol{\varepsilon}} = \frac{1}{2}(\nabla\mathbf{U} + (\nabla\mathbf{U})^{\mathrm{T}})$$

Cement and Concrete Research 95 (2017) 9–17

Contents lists available at ScienceDirect

Cement and Concrete Research

journal homepage: www.elsevier.com/locate/cemconres

ELSEVIER

Analysis of shear rate inside a concrete truck mixer

Jon Elvar Wallevik[a,*], Olafur Haralds Wallevik[b]

[a] ICI Rheocenter, Innovation Center Iceland, Arleynir 2, Reykjavik IS-112, Iceland
[b] ICI Rheocenter, Reykjavik University and Innovation Center Iceland, Arleynir 2, Reykjavik IS-112, Iceland

ARTICLE INFO

Article history:
Received 28 November 2016
Accepted 10 February 2017
Available online 20 February 2017

Keywords:
Truck mixer
Shear rate
Fresh concrete
Rheology
Finite volume method

ABSTRACT

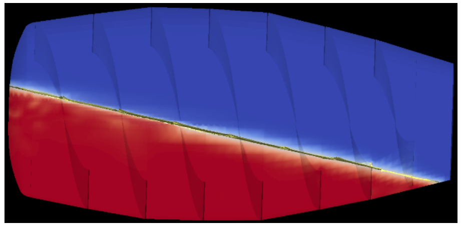
In addition to the mixing energy applied to the fresh concrete (i.e. shearing during mixing), the shear history after mixing is also important. This applies especially to binder rich concretes like the different types of high performance concrete (HPC). With this in mind, the shear rate is analyzed inside a drum of a concrete truck mixer. The objective is to better understand the effect of transport of fresh concrete, from the ready mix plant to the building site. The analysis reveals the effect of different drum charge volume and drum rotational speed. Also, the effect of yield stress and plastic viscosity is investigated. The work shows that the shear rate decreases in an exponential manner with increasing drum charge volume. It is also shown that for a given drum speed, the shear rate decreases both with increasing plastic viscosity and yield stress.

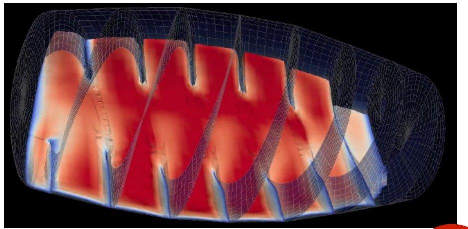
Rate of work (mechanical power)

Mase, G.T. and Mase, G.E. [13]; Malvern, L.E. [8]

$$P = \iiint_V \rho\, \mathbf{g} \cdot \mathbf{v}\, dV + \iint_{\partial V} \mathbf{t} \cdot \mathbf{v}\, dA$$

V = Volume of concrete

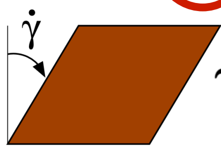




Wallevik, J.E., Ref. [11] pp. 386 – 389

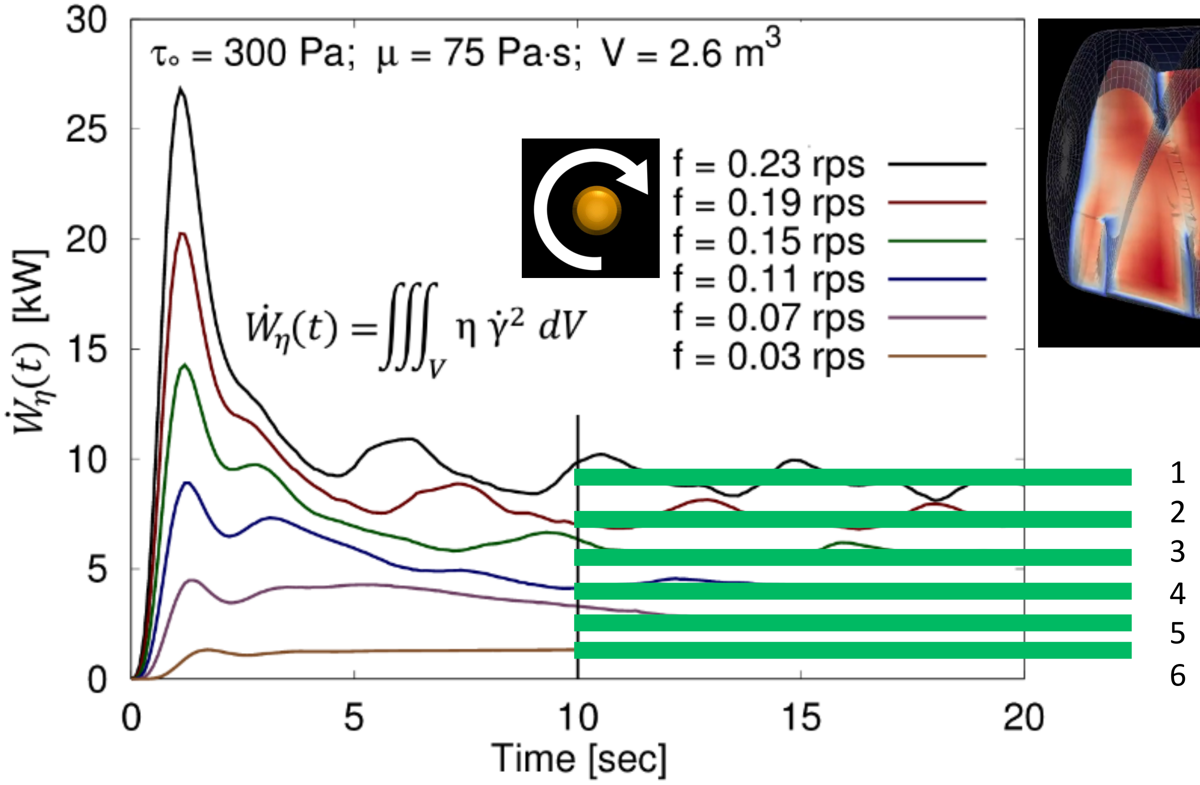
$$P = \iiint_V \rho \frac{d}{dt}\left[\frac{\mathbf{v} \cdot \mathbf{v}}{2}\right] dV + \iiint_V \eta\, \dot{\gamma}^2\, dV$$

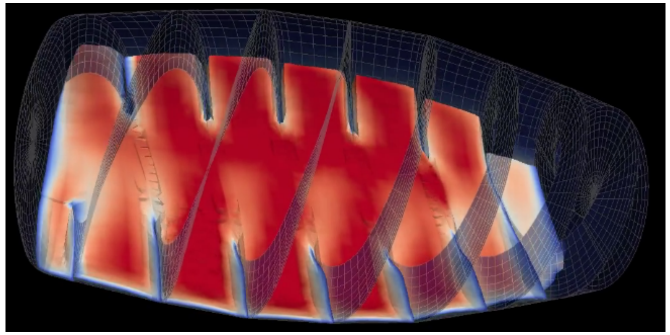
$$\eta = \mu + \tau_0 / \dot{\gamma}$$



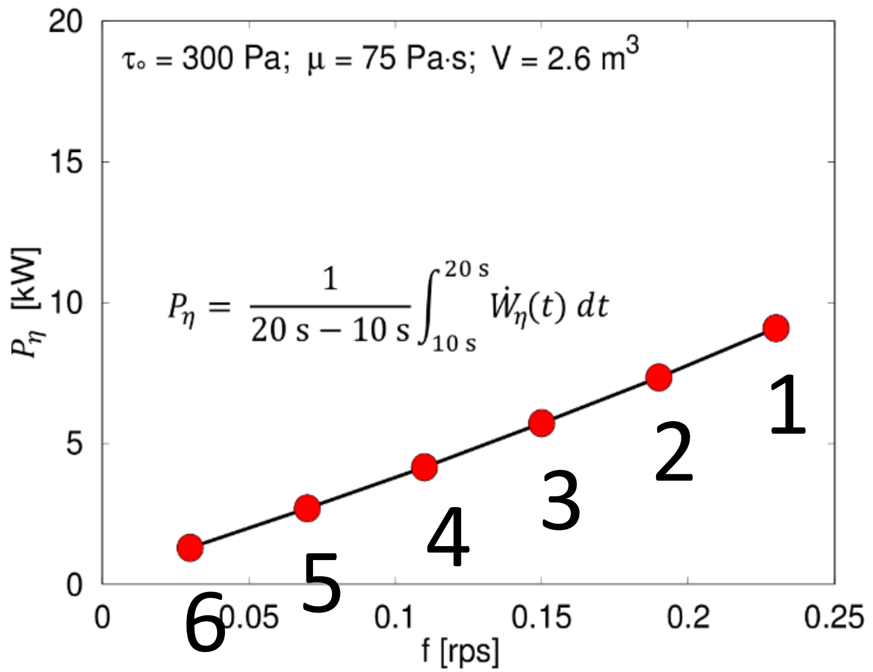
$$\dot{\gamma} = \sqrt{2\, \dot{\boldsymbol{\varepsilon}} : \dot{\boldsymbol{\varepsilon}}}$$

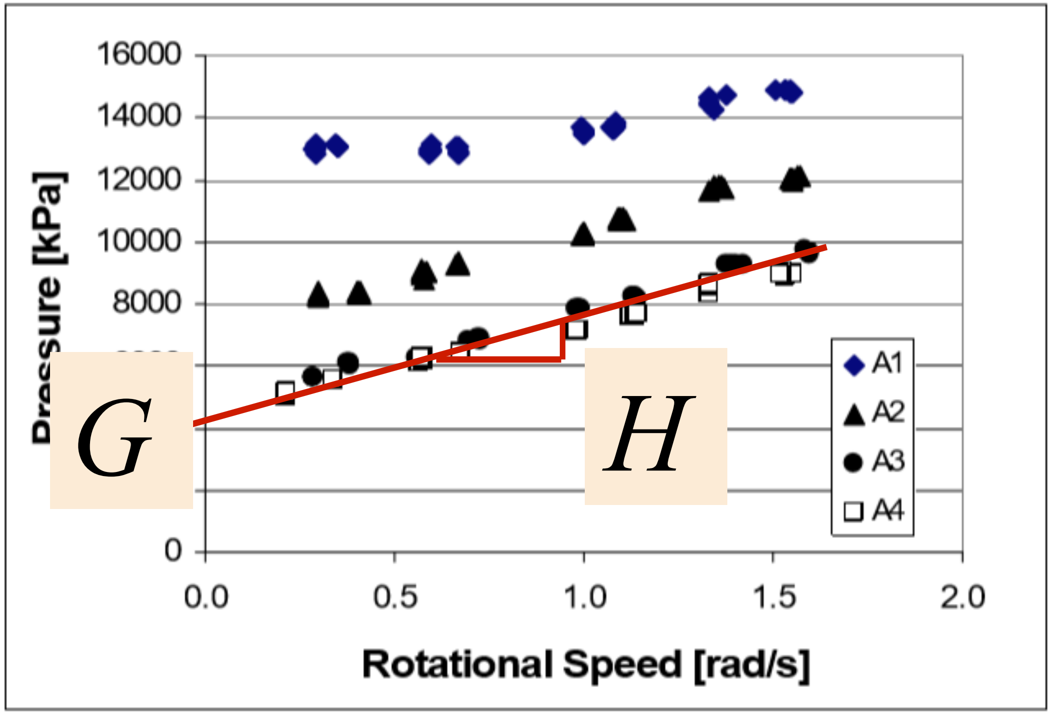
To generate quantifiable data for comparison

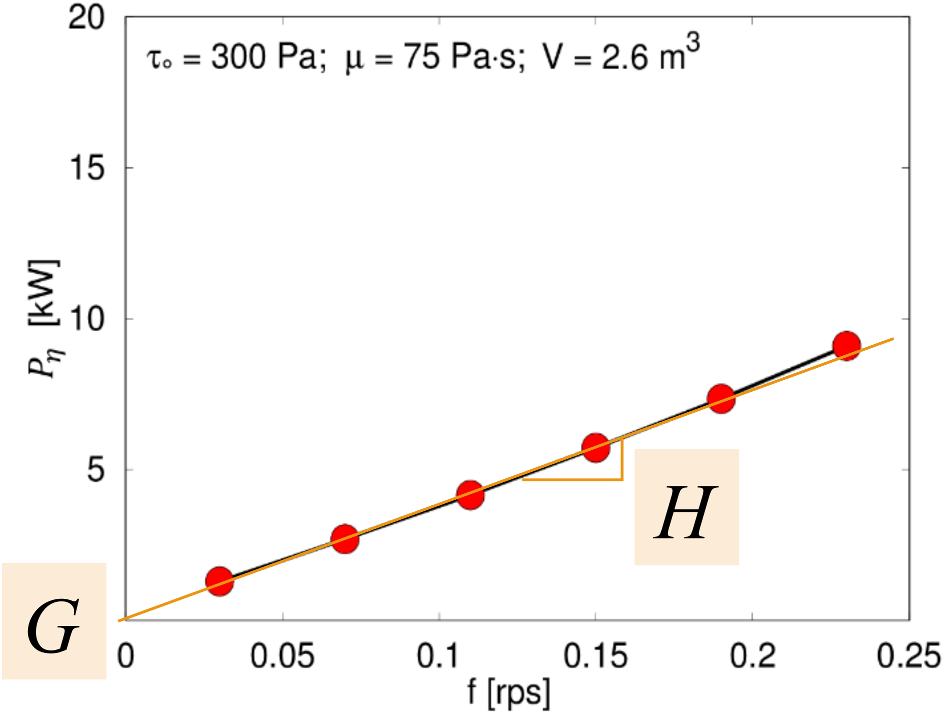


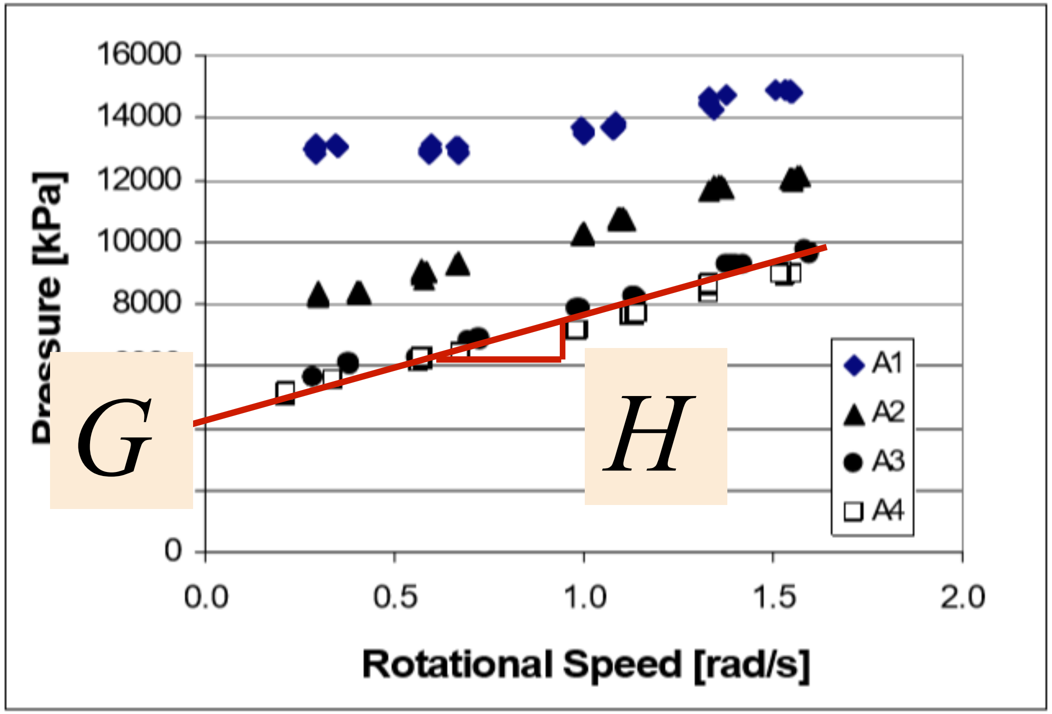


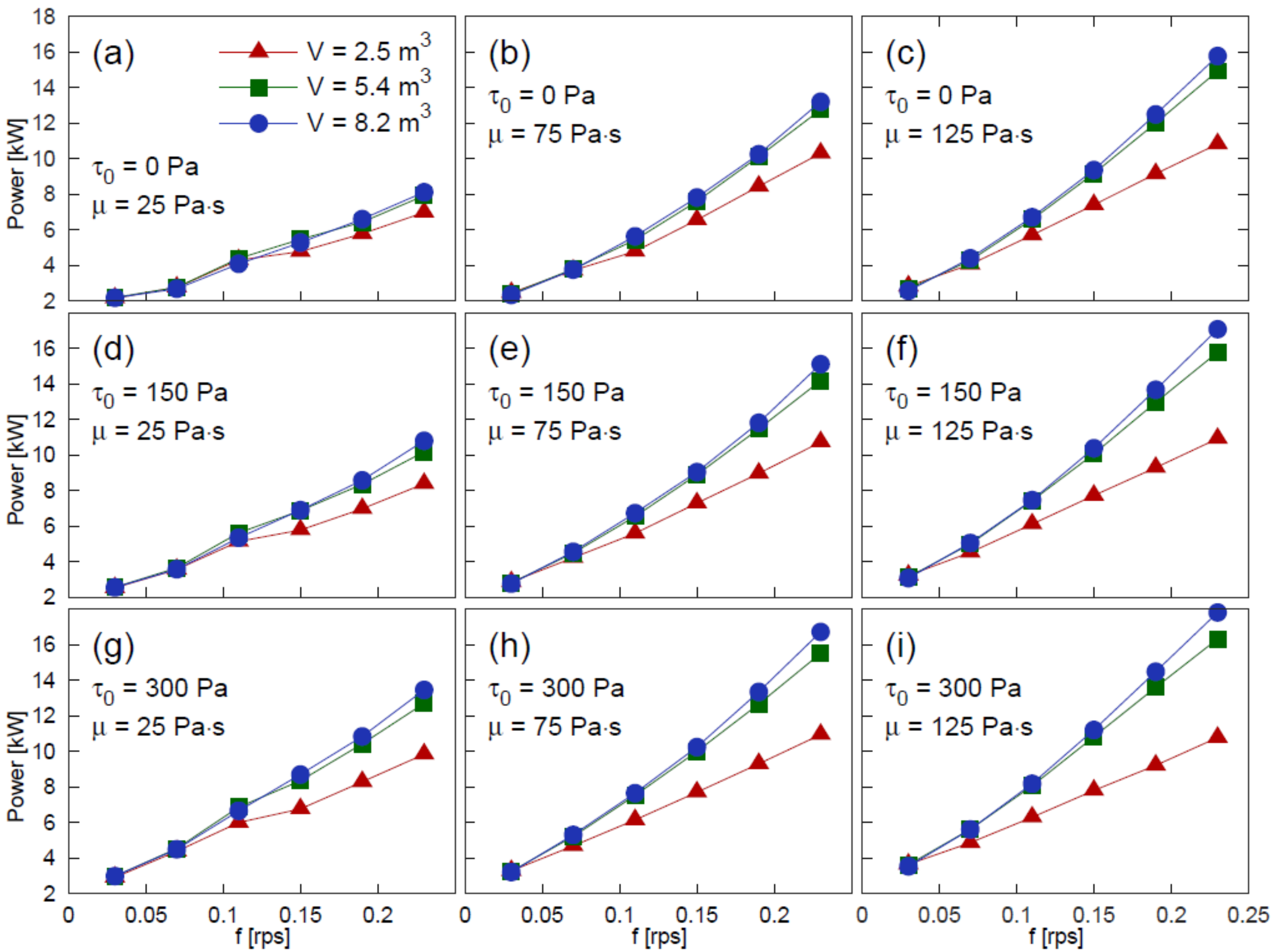
$$P = \frac{1}{20\text{ s} - 10\text{ s}} \int_{10\text{ s}}^{20\text{ s}} \dot{W}(t)\,dt$$ = Power at equilibrium

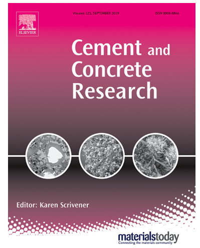

τ∘ = 300 Pa; μ = 75 Pa·s; V = 2.6 m3
$P_\eta = \frac{1}{20\text{ s} - 10\text{ s}} \int_{10\text{ s}}^{20\text{ s}} \dot{W}_\eta(t)\, dt$
P_η [kW]
f [rps]
20
15
10
5
0
0
0.05
0.1
0.15
0.2
0.25
1
2
3
4
5
6


16000
14000
12000
10000
8000
0
0.0
0.5
1.0
1.5
2.0
Rotational Speed [rad/s]
A1
A2
A3
A4
G
H


τ∘ = 300 Pa; μ = 75 Pa·s; V = 2.6 m3
Pη [kW]
f [rps]
G
H


Pressure [kPa]
Rotational Speed [rad/s]
A1
A2
A3
A4
G
H



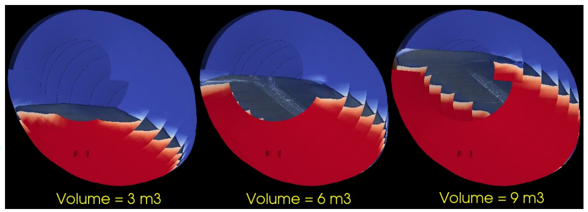


Drum charge volume:

$V = 2.5\ m^3$,

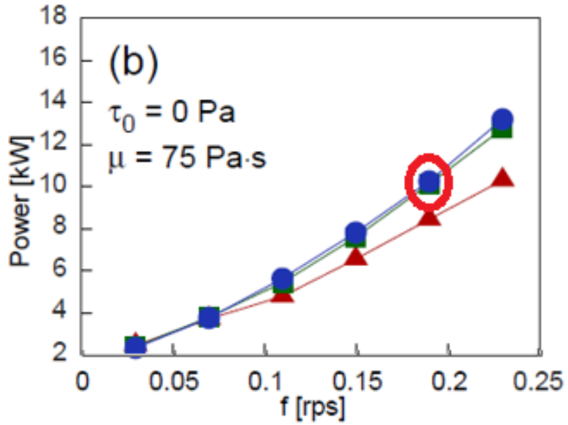
$V = 5.4\ m^3$

$V = 8.2\ m^3$

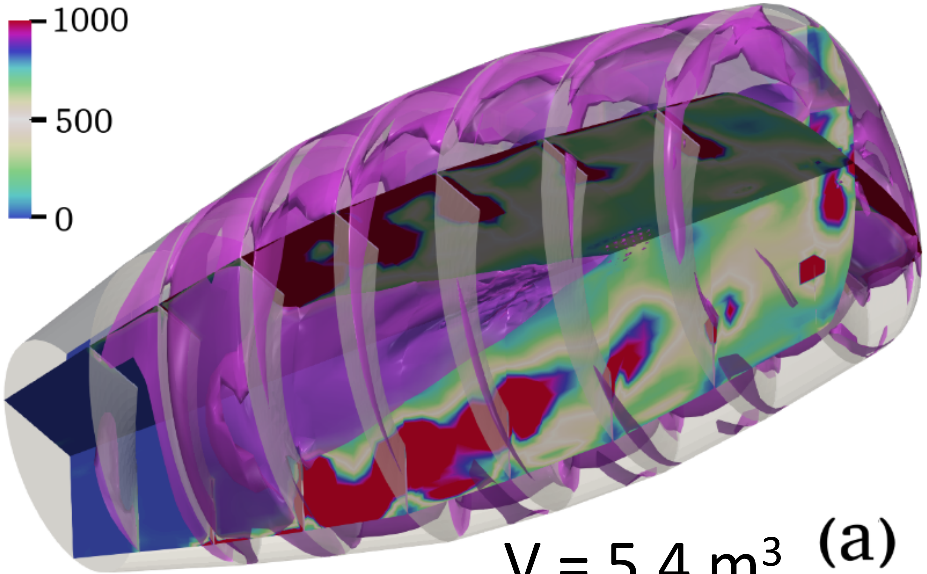


Cross-section of $\eta\,\dot{\gamma}^2$ (in [Pa/s])
tau0 = 0 Pa and mu = 75 Pa.s, *f* = 0.19 rps and time t = 16.5 s,

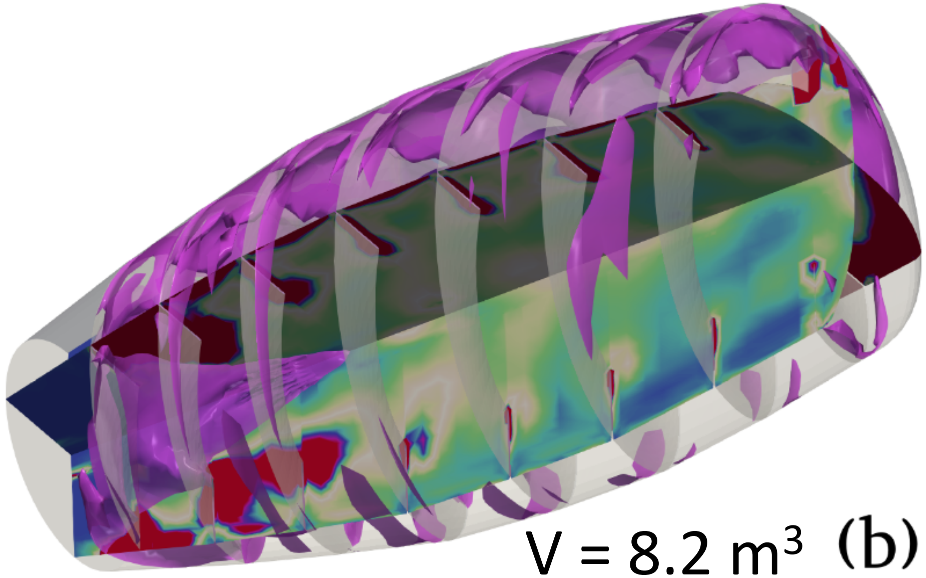
$$\iiint_V \eta\,\dot{\gamma}^2\, dV$$



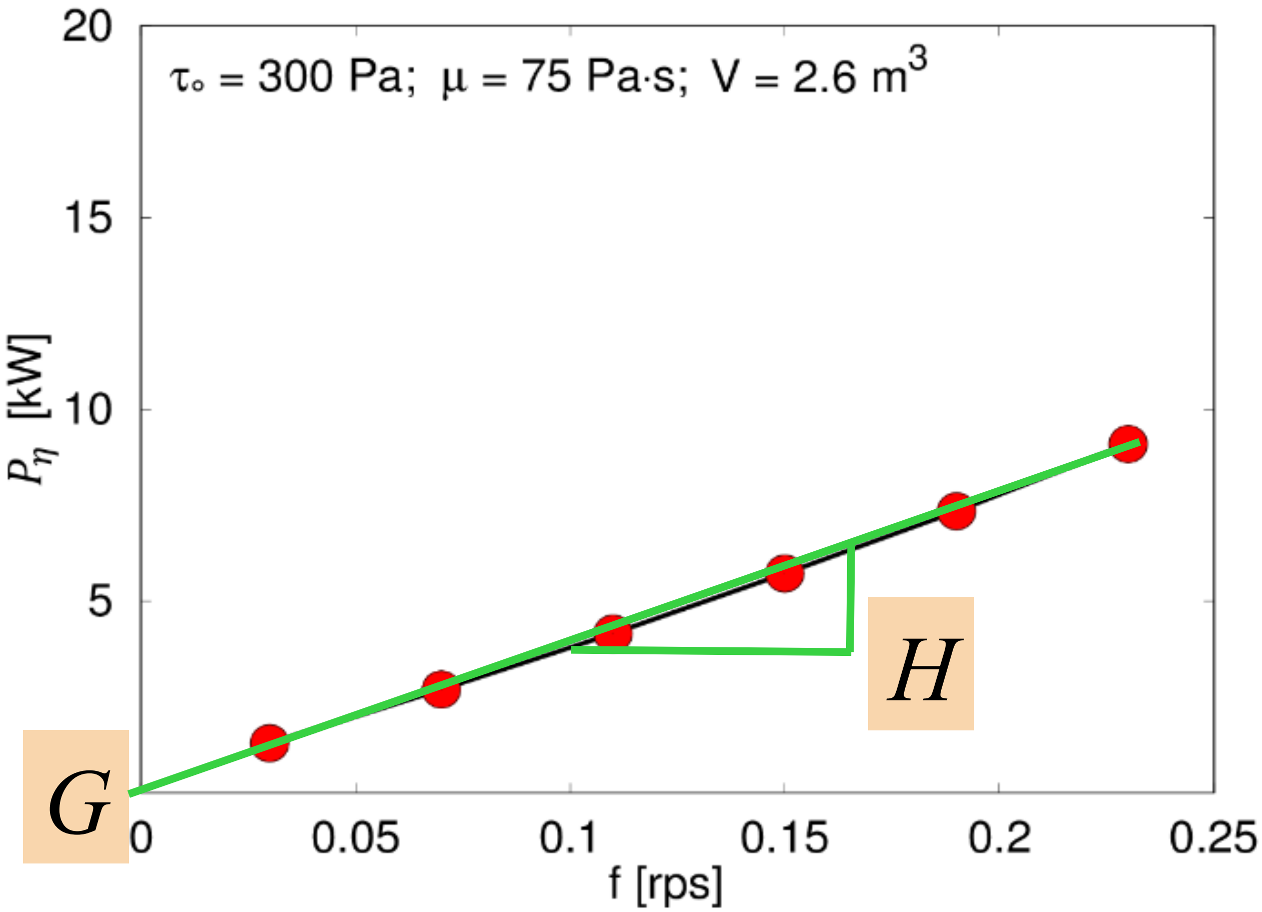
Increased volume *V* results in lower intensity of $\eta\,\dot{\gamma}^2$

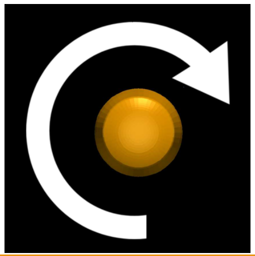


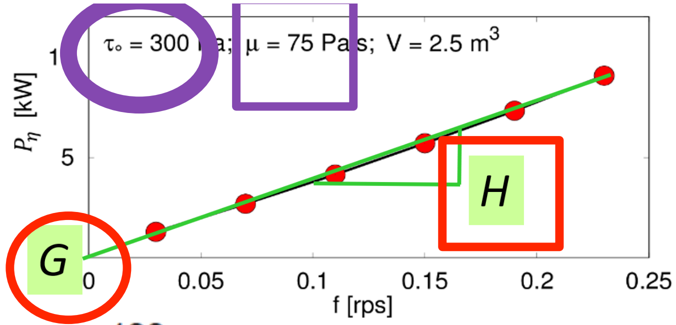
V = 5.4 m³ (a)



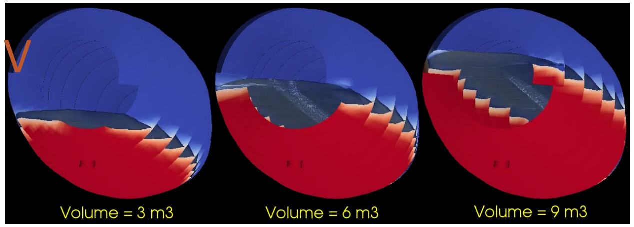
V = 8.2 m³ (b)

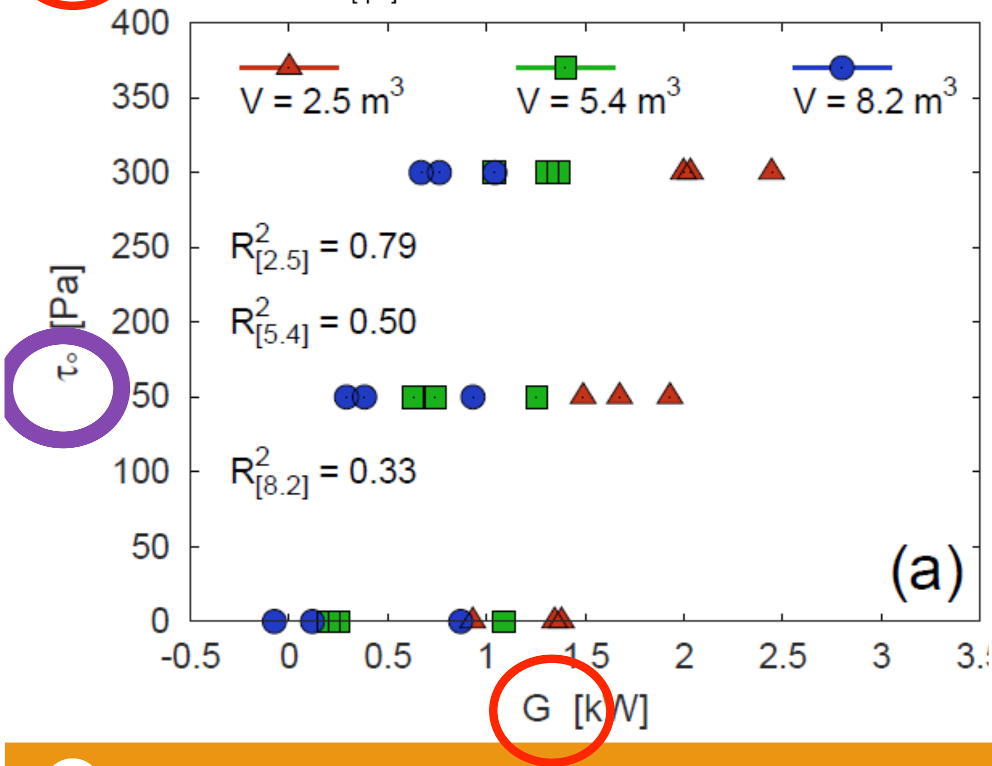

τ∘ = 300 Pa; μ = 75 Pa·s; V = 2.6 m3
P_η [kW]
f [rps]
20
15
10
5
0
0.05
0.1
0.15
0.2
0.25
G
H

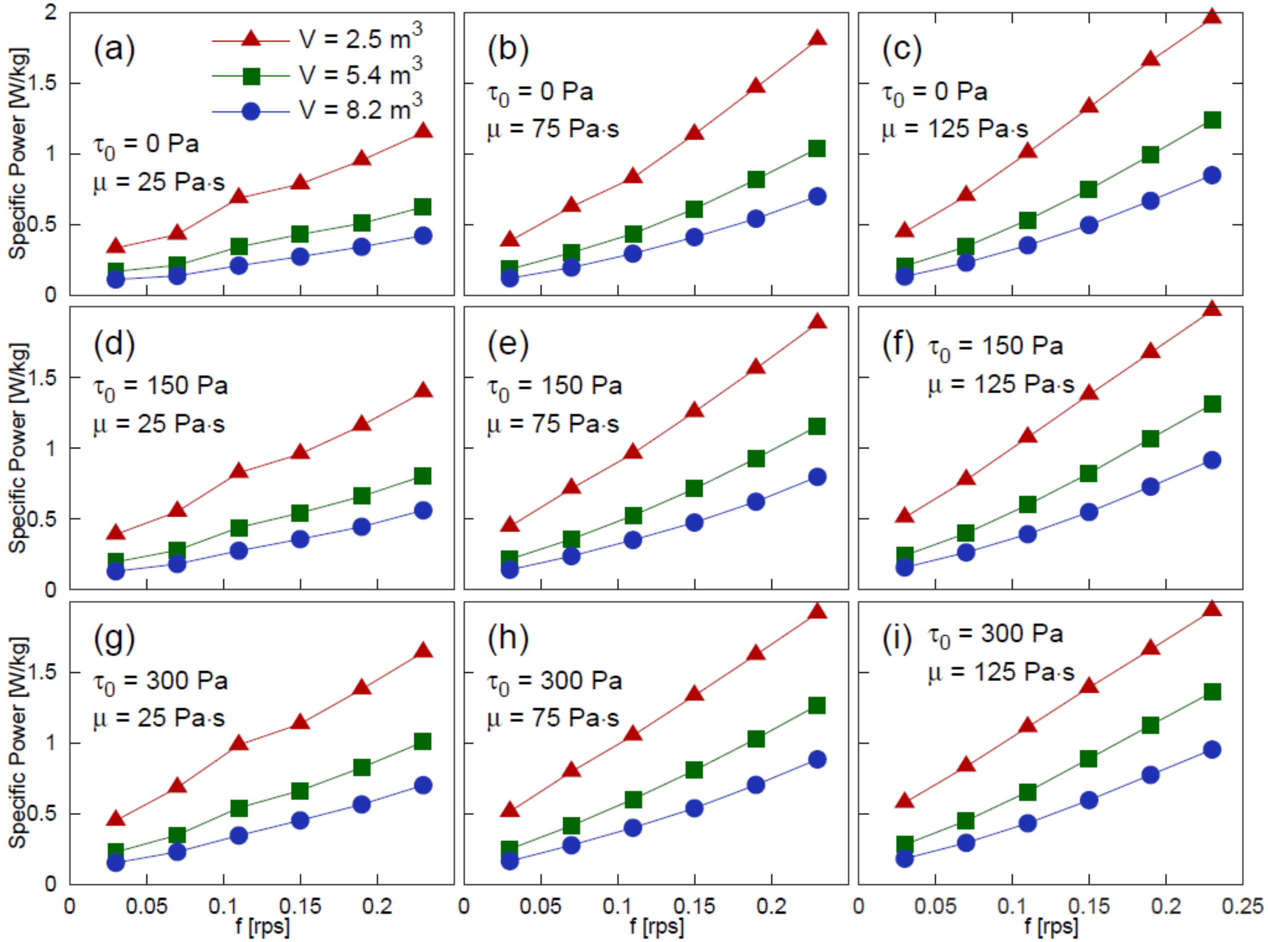


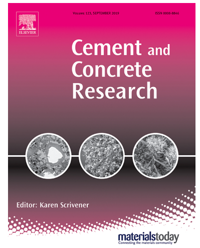


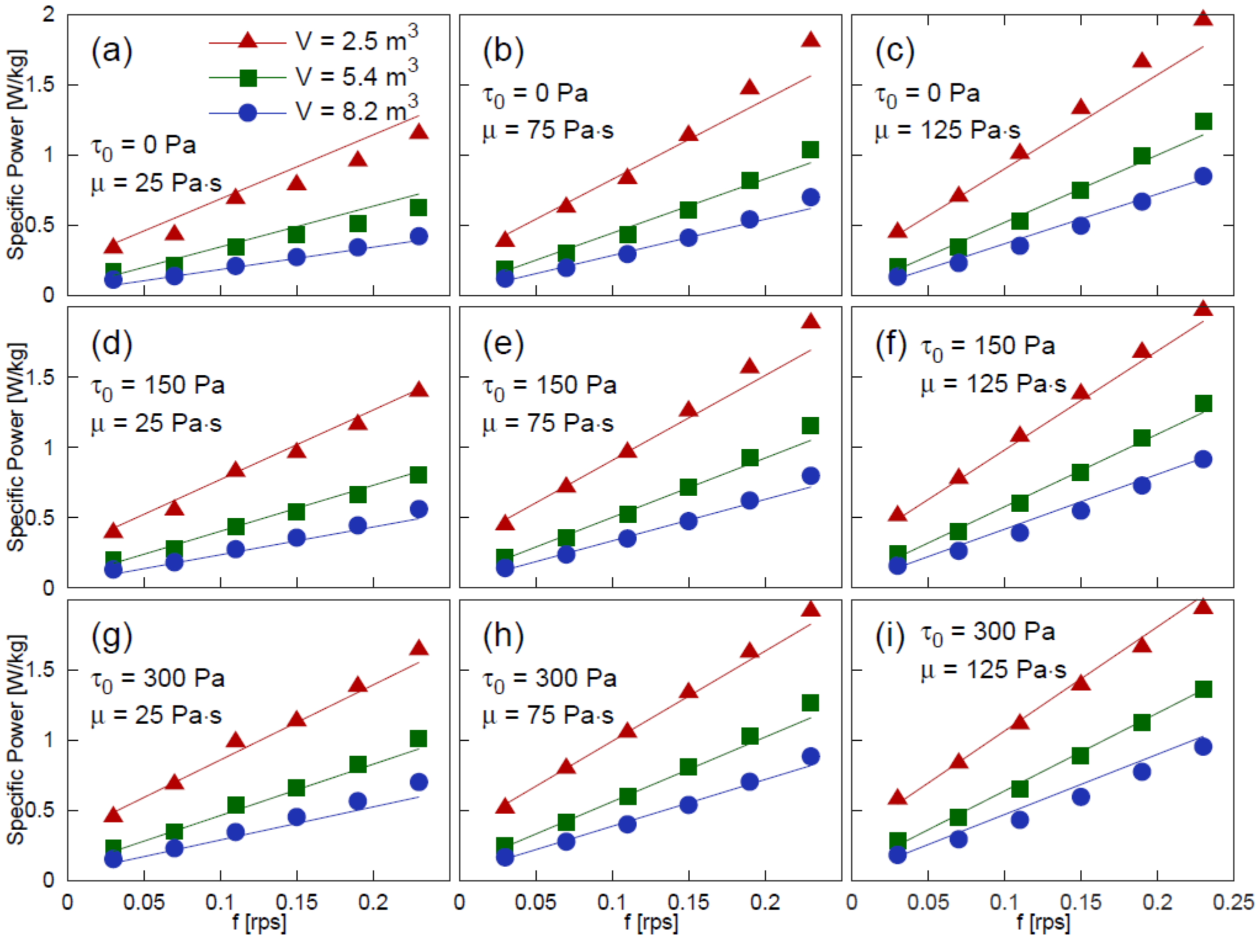
Drum charge volume: V = 2.5 m^3, V = 5.4 m^3 and V = 8.2 m^3

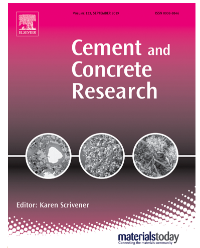





(a)
V = 2.5 m3
V = 5.4 m3
V = 8.2 m3
τ0 = 0 Pa
μ = 25 Pa·s
(b)
τ0 = 0 Pa
μ = 75 Pa·s
(c)
τ0 = 0 Pa
μ = 125 Pa·s
(d)
τ0 = 150 Pa
μ = 25 Pa·s
(e)
τ0 = 150 Pa
μ = 75 Pa·s
(f) τ0 = 150 Pa
μ = 125 Pa·s
(g)
τ0 = 300 Pa
μ = 25 Pa·s
(h)
τ0 = 300 Pa
μ = 75 Pa·s
(i) τ0 = 300 Pa
μ = 125 Pa·s
Specific Power [W/kg]
f [rps]
0
0.05
0.1
0.15
0.2
0.25
0.5
1
1.5
2


Cement and Concrete Research





$$G = \rho_1 \left(q_6\, \tau_0 + \frac{q_7}{V} + \frac{q_8}{\mu + q_9} \right)$$

$$H = \rho_1 V \left(q_1\, \tau_0 + q_2\, \mu + q_3\, (V + q_4)^2 + \frac{q_5}{V} \right)$$

Specific values

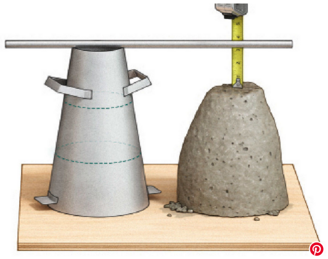
g = G/(rho*V)

h = H/(rho*V)

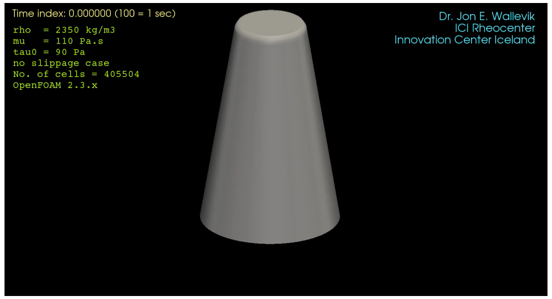
p = P /(rho*V)

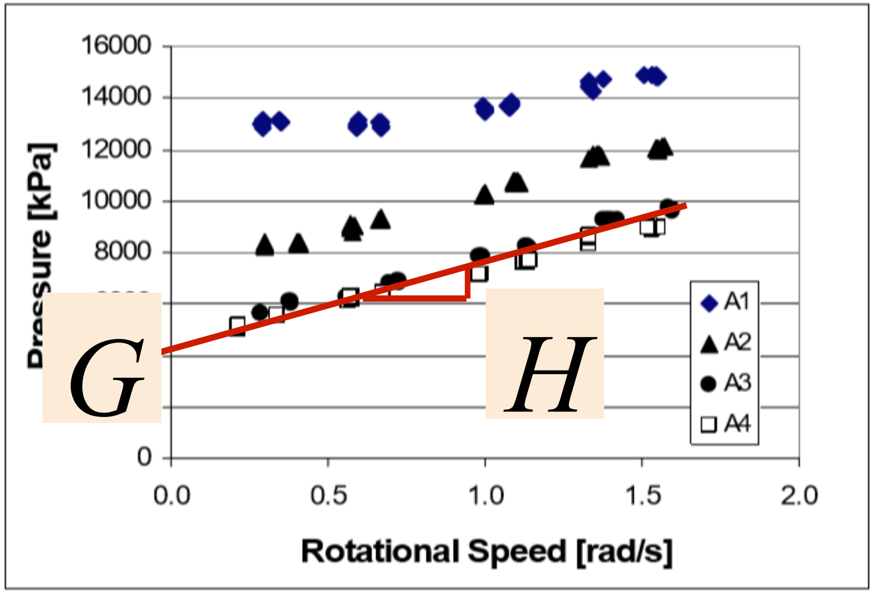
p = h f + g

$$G = Q_1\,\tau_0$$



$$H = Q_2\,\mu$$





$$G = \rho_1 \left(q_6\,\tau_0 + \frac{q_7}{V} + \frac{q_8}{\mu + q_9} \right)$$

$$H = \rho_1 V \left(q_1\,\tau_0 + q_2\,\mu + q_3\,(V + q_4)^2 + \frac{q_5}{V} \right)$$

Conclusions

Both the yield stress τ_0 and the plastic viscosity μ do influence the slope H, to similar or the same extent

- This can explain why it has been difficult to experimentally correlate only the plastic viscosity μ to the H value, as reported in [18, 19, 20]

Although the plastic viscosity μ affects the G value, its influence is only minor

- This can explain why it has been easier (relatively to the above) to experimentally correlate yield stress τ_0 to the G value, as reported in [18, 19, 20].

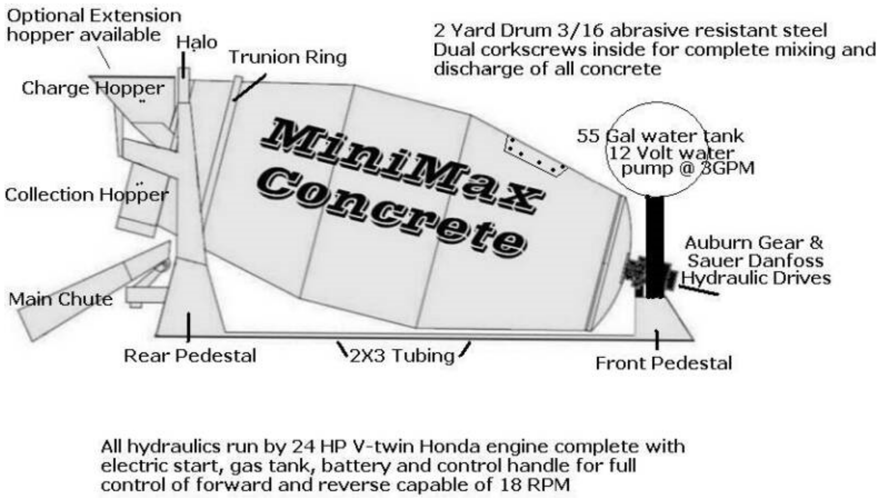
$$\boxed{G = Q_1\,\tau_0} \qquad G = \rho_1 \left(q_6\,\tau_0 + \frac{q_7}{V} + \frac{q_8}{\mu + q_9} \right)$$

$$\boxed{H = Q_2\,\mu} \qquad H = \rho_1 V \left(q_1\,\tau_0 + q_2\,\mu + q_3\,(V + q_4)^2 + \frac{q_5}{V} \right)$$

Icelandic Research Fund

NORCEM HEIDELBERGCEMENT Group

Icelandic High Performance Computing (IHPC) - http://ihpc.is



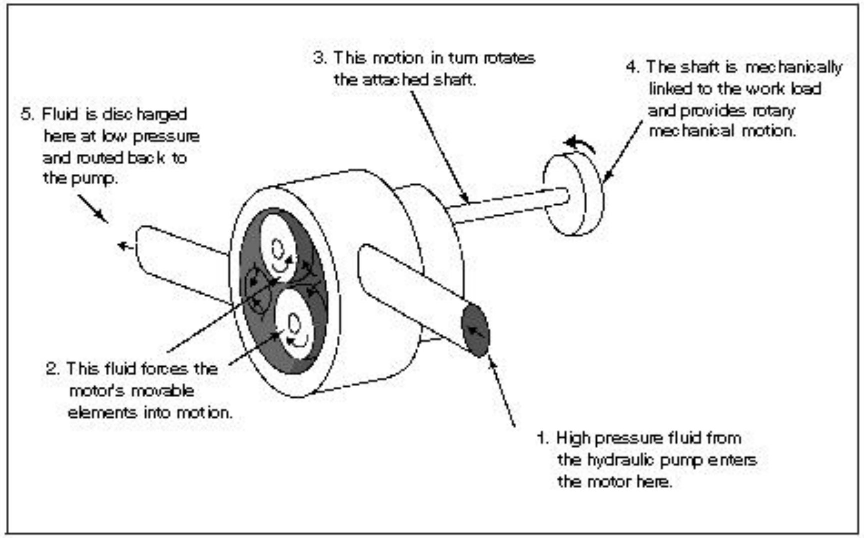
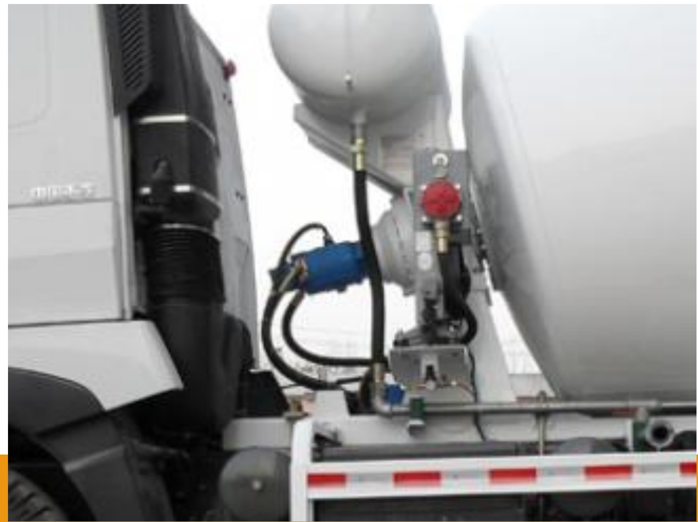
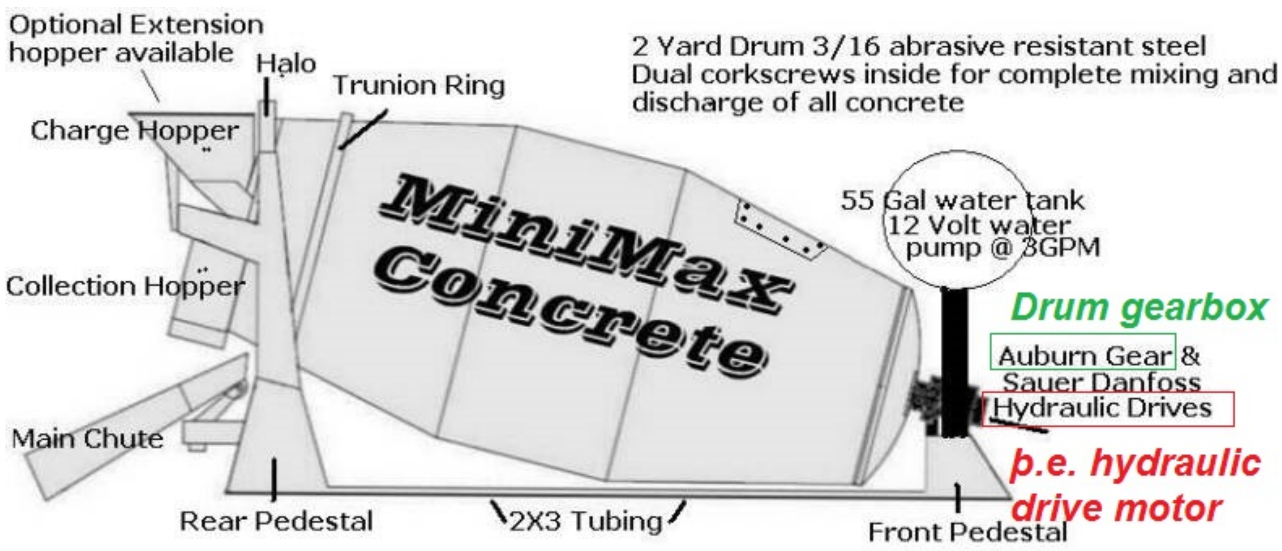


Figure 4-9. Basic operations of a hydraulic motor





All hydraulics run by 24 HP V-twin Honda engine complete with electric start, gas tank, battery and control handle for full control of forward and reverse capable of 18 RPM