CFD of high shear mixer geometries for fast moving consumer goods

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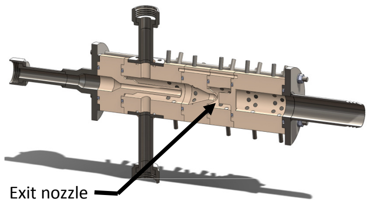
Unilever is interested in the application of CFD for a number of process areas:
Newtonian fluids (i.e. Backwashing)
Non-Newtonian (structured) liquids (gels, emulsions etc. laminar or turbulent)

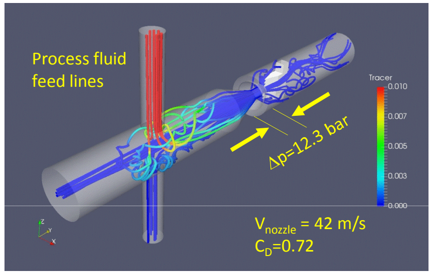
3 non-Newtonian viscosity models have been implemented into **CODE_SATURNE**

$\boldsymbol{\tau} \propto \mathbf{S}$	Newtonian
$\boldsymbol{\tau} \propto \lvert\mathbf{S}\rvert^{n-1}\mathbf{S}$	Power law
$\boldsymbol{\tau} - \boldsymbol{\tau}_0 \propto \lvert\mathbf{S}\rvert^{n-1}\mathbf{S}$	Herschel-Bulkley
$\boldsymbol{\tau} \propto \left(a + b\lvert\mathbf{S}\rvert^{n-1}\right)\mathbf{S}$	Sisko

Static inline mixer

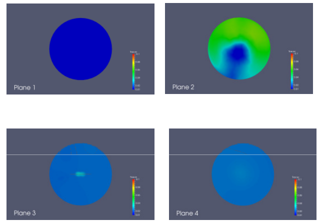


Area : 2.4 mm²
Re = 81, 500

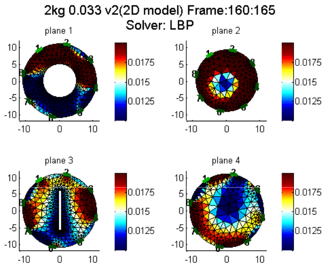


Downstream mixing

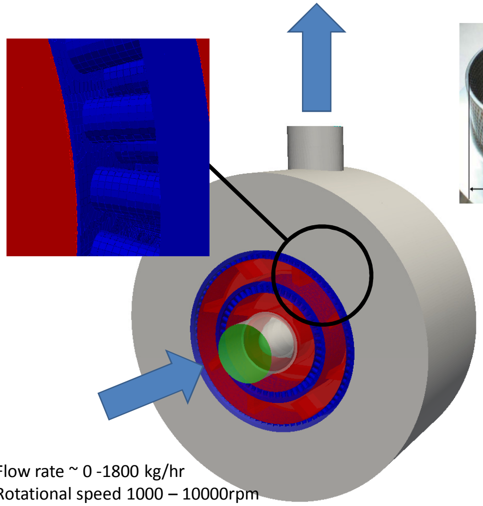
URANS: k-ε turbulence model
(2.1 million cells)



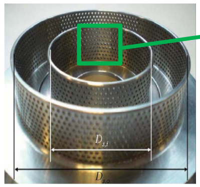
Typical ERT results *(P. Martin, (UoM))*



High shear batch mixer



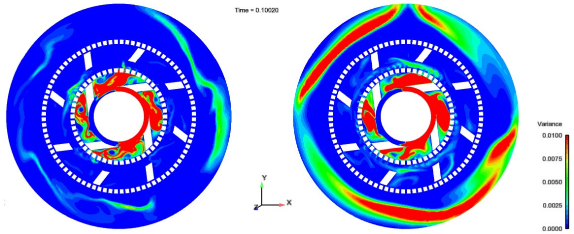
Flow rate ~ 0 -1800 kg/hr
Rotational speed 1000 – 10000rpm



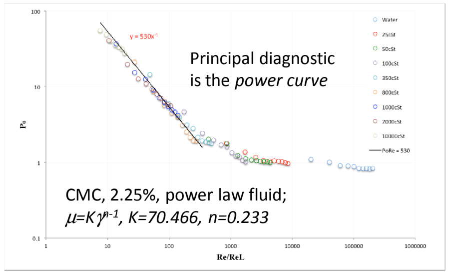
860 Screen holes,
ϕ=1.588mm

Rotor OD=64mm

rms mass fraction fluctuations



RSM-SSG **EVM-SST-modified**



Principal diagnostic is the *power curve*

CMC, 2.25%, power law fluid;
$\mu = K\dot{\gamma}^{n-1}$, *K=70.466, n=0.233*

- These simulations (2D & 3D) use *Sliding meshes*
  - Important to get laminar ***extensional*** and ***folding*** flow
  - 2D : 180x10³ cells on 64 cores, 12.5Hrs per simulated revolution (CSF)
  - 3D : 7.5x10⁶ cells on 960 cores, 8.5 Hrs per simulated revolution (HPC)
- Where turbulent, (curvature compensated) SST and SSG models are used
- Modified wall treatments

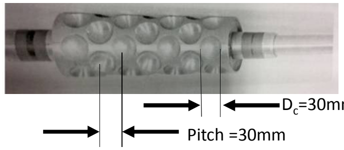
$$\nu = K\dot{\gamma}^{n-1} \qquad \frac{U}{u_\tau} = A(n)\ln\left(y^+\right) + B(n) \qquad \left(y^+\right)^{2-n} = \frac{u_\tau^{2-n}y}{K}$$

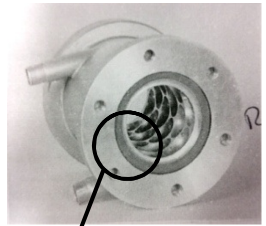
Cavity transfer mixer (CTM)

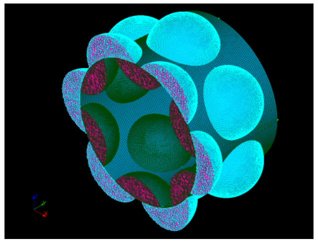
Mixing comes from movement between cavities

Flow tortuosity & high shear improves mixing

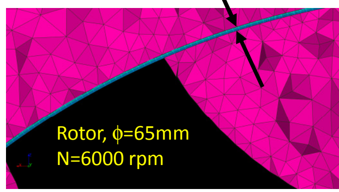
Goal: maximize mixing, minimize Δp, power and remove leak path.







Annular gap = 0.15mm



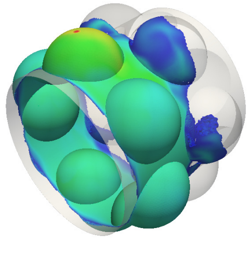
Model : k-ε turbulence model with rotation correction
3D : 2.86x10⁶ cells on 144 cores, 9Hrs per simulated revolution

Validation:

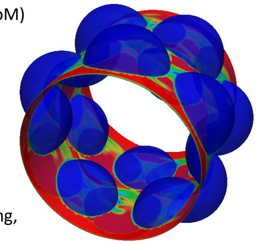
Pilot scale CTM (CEAS, UoM)

Rotor Ø = 65mm
Cavity Ø = 30 mm
Annulus = 0.15mm
N = 100 Hz, Q = 100 l/h
60 % g/w solution
Re_{CAV} = 66,450

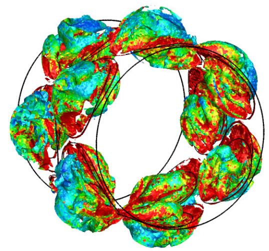
Parametric studies: Mixing, Power/ΔP vs. N, Q



Tracer mass fraction
(after 10 revolutions)



Strain rate distribution
(after 10 revolutions)



Iso-Q, coloured by vorticity
(after 10 revolutions)