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Viscosity of some ﬂuids
Fluid Air (at Benzene Water (at 18 ◦ C) Olive oil (at 20 ◦ C) Motor oil SAE 50 Honey Ketchup Peanut butter Tar Earth lower mantle 18 ◦ C) Viscosity [cP] 0. 02638 0. 5 1 84 540 2000–3000 50000–70000 150000–250000 3 × 1010 3 × 1025

Table: Viscosity of some ﬂuids
Josef M´lek a Non-Newtonian ﬂuids

Viscosity of some ﬂuids Models with variable viscosity Diﬀerential type models Rate type models Integral type models Download

Shear dependent viscosity Models with pressure dependent viscosity Models with stress dependent viscosity Models with discontinuous rheology

Models with variable viscosity

General form: T = −pI + 2µ(D, T)D
S

(2. 1)

Particular models mainly developed by chemical engineers.

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Ostwald–de Waele power law
¨ Wolfgang Ostwald. Uber die Geschwindigkeitsfunktion der Viskosit¨t disperser Systeme. I. Colloid Polym. Sci., 36: 99–117, a 1925 A. de Waele. Viscometry and plastometry. J. Oil Colour Chem. Assoc., 6: 33–69, 1923 µ(D) = µ0 | D| n−1 (2. 2)

Fits experimental data for: ball point pen ink, molten chocolate, aqueous dispersion of polymer latex spheres

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Carreau Carreau–Yasuda
Pierre J. Carreau. Rheological equations from molecular network theories. J.
Rheol., 16(1): 99–127, 1972 Kenji Yasuda. Investigation of the analogies between viscometric and linear viscoelastic properties of polystyrene ﬂuids. PhD thesis, Massachusetts Institute of Technology. Dept. of Chemical Engineering., 1979 µ0 − µ∞ (1 + α | D| 2 ) 2 n n−1 a

µ(D) = µ∞ +

(2. 3) (2. 4)

µ(D) = µ∞ + (µ0 − µ∞ ) (1 + α | D| a ) Fits experimental data for: molten polystyrene Josef M´lek a Non-Newtonian ﬂuids

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Eyring
Henry Eyring. Viscosity, plasticity, and diﬀusion as examples of absolute reaction rates. J. Chem. Phys., 4(4): 283–291, 1936 Francis Ree, Taikyue Ree, and Henry Eyring. Relaxation theory of transport problems in condensed systems. Ind. Eng. Chem., 50(7): 1036–1040, 1958 µ(D) = µ∞ + (µ0 − µ∞ ) arcsinh (α | D|) α | D| arcsinh (α1 | D|) arcsinh (α2 | D|) µ(D) = µ0 + µ1 + µ2 α1 | D| α2 | D| (2. 5) (2. 6)

Fits experimental data for: napalm (coprecipitated aluminum salts of naphthenic and palmitic acids; jellied gasoline), 1% nitrocelulose in 99% butyl acetate Josef M´lek a Non-Newtonian ﬂuids

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Cross

Malcolm M. Cross. Rheology of non-newtonian ﬂuids: A new ﬂow equation for pseudoplastic systems. J. Colloid Sci., 20(5): 417–437, 1965 µ(D) = µ∞ + µ0 − µ∞ 1 + α | D| n (2. 7)

Fits experimental data for: aqueous polyvinyl acetate dispersion, aqueous limestone suspension

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Sisko

A. W. Sisko. The ﬂow of lubricating greases. Ind. Eng. Chem., 50(12): 1789–1792, 1958 µ(D) = µ∞ + α | D| n−1 Fits experimental data for: lubricating greases (2. 8)

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Barus

C. Barus. Isotherms, isopiestics and isometrics relative to viscosity. Amer. J. Sci., 45: 87–96, 1893 µ(T) = µref eβ(p−pref ) Fits experimental data for: mineral oils1 , organic liquids2 (2. 9)

Michael M. Khonsari and E. Richard Booser. Applied Tribology: Bearing Design and Lubrication. John Wiley & Sons Ltd, Chichester, second edition, 2008 2 P. W. Bridgman. The eﬀect of pressure on the viscosity of forty-four pure liquids. Proc. Am. Acad. Art. Sci., 61(3/12): 57–99, FEB-NOV 1926 Josef M´lek a Non-Newtonian ﬂuids

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Ellis
Seikichi Matsuhisa and R. Byron Bird. Analytical and numerical solutions for laminar ﬂow of the non-Newtonian Ellis ﬂuid. AIChE J., 11(4): 588–595, 1965 µ(T) = µ0 1 + α | Tδ | n−1 (2. 10)

Fits experimental data for: 0. 6% w/w carboxymethyl cellulose (CMC) solution in water, poly(vynil chloride)3

T. A. Savvas, N. C. Markatos, and C. D. Papaspyrides. On the ﬂow of non-newtonian polymer solutions. Appl. Math. Modelling, 18(1): 14–22, 1994 Josef M´lek a Non-Newtonian ﬂuids

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Glen

J. W. Glen. The creep of polycrystalline ice. Proc. R. Soc. A-Math. Phys. Eng. Sci., 228(1175): 519–538, 1955 µ(T) = α | Tδ | n−1 Fits experimental data for: ice (2. 11)

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Seely

Gilbert R. Seely. Non-newtonian viscosity of polybutadiene solutions. AIChE J., 10(1): 56–60, 1964 µ(T) = µ∞ + (µ0 − µ∞ ) e − | Tδ |
τ0

(2. 12)

Fits experimental data for: polybutadiene solutions

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Blatter
Erin C. Pettit and Edwin D. Waddington. Ice ﬂow at low deviatoric stress. J. Glaciol., 49(166): 359–369, 2003 H Blatter. Velocity and stress-ﬁelds in grounded glaciers – a simple algorithm for including deviatoric stress gradients. J. Glaciol., 41(138): 333–344, 1995 µ(T) = 2

A | Tδ | +
2 τ0
n−1 2

(2. 13)

Fits experimental data for: ice

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Bingham Herschel–Bulkley
C. E. Bingham. Fluidity and plasticity. McGraw–Hill, New York, 1922 Winslow H. Herschel and Ronald Bulkley. Konsistenzmessungen von Gummi-Benzoll¨sungen. Colloid Polym. Sci., 39(4): 291–300, o August 1926 | Tδ
| > τ ∗ | Tδ | ≤ τ ∗ if and only if Tδ = τ ∗ if and only if D= 0 D + 2µ(| D|)D | D|

(2. 14)

Fits experimental data for: paints, toothpaste, mango jam
Santanu Basu and U. S. Shivhare. Rheological, textural, micro-structural and sensory properties of mango jam. J. Food Eng., 100(2): 357–365, 2010 Josef M´lek a Non-Newtonian ﬂuids

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Rivlin–Ericksen ﬂuids

Rivlin–Ericksen
R. S. Rivlin and J. L. Ericksen. Stress-deformation relations for isotropic materials. J. Ration. Mech. Anal., 4: 323–425, 1955 R. S. Rivlin and K. N. Sawyers. Nonlinear continuum mechanics of viscoelastic ﬂuids. Annu. Rev. Fluid Mech., 3: 117–146, 1971 General form: T = −pI + f(A1 A2 A3 . . . ) (3. 1) where A1 = 2D dAn−1 + An−1 L + L An−1 An = dt (3. 2a) (3. 2b)

d where dt denotes the usual Lagrangean time derivative and L is the velocity gradient. Josef M´lek a Non-Newtonian ﬂuids

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Rivlin–Ericksen ﬂuids

Criminale–Ericksen–Filbey

William O. Criminale, J. L. Ericksen, and G. L. Filbey. Steady shear ﬂow of non-Newtonian ﬂuids. Arch. Rat. Mech. Anal., 1: 410–417, 1957 T = −pI + α1 A1 + α2 A2 + α3 A2 1 (3. 3)

Fits experimental data for: polymer melts (explains mormal stress diﬀerences)

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Rivlin–Ericksen ﬂuids

Reiner–Rivlin

M. Reiner. A mathematical theory of dilatancy. Am. J. Math., 67(3): 350–362, 1945 T = −pI + 2µD + µ1 D2 Fits experimental data for: N/A (3. 4)

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Maxwell, Oldroyd, Burgers Giesekus Phan-Thien–Tanner Johnson–Segalman Johnson–Tevaarwerk

Maxwell
J. Clerk Maxwell. On the dynamical theory of gases. Philos. Trans. R. Soc., 157: 49–88, 1867

T = −pI + S S + λ1 S = 2µD dM − LM − ML dt Fits experimental data for: N/A M = def Josef M´lek a Non-Newtonian ﬂuids

(4. 1a) (4. 1b)

(4. 2)

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Oldroyd-B

J. G. Oldroyd. On the formulation of rheological equations of state. Proc. R. Soc. A-Math. Phys. Eng. Sci., 200(1063): 523–541, 1950

T = −πI + S S + λS = η1 A1 + η2 A1 Fits experimental data for: N/A

(4. 3a) (4. 3b)

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Oldroyd 8-constants
J. G. Oldroyd. On the formulation of rheological equations of state. Proc. R. Soc. A-Math. Phys. Eng. Sci., 200(1063): 523–541, 1950 T = −πI + S λ3 λ5 λ6 (DS + SD) + (Tr S) D + (S : D) I 2 2 2 λ7 (D : D) I = −µ D + λ2 D + λ4 D2 + 2 (4. 4a)

S + λ1 S +

(4. 4b)

Fits experimental data for: N/A
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Burgers
J. M. Burgers. Mechanical considerations – model systems – phenomenological theories of relaxation and viscosity. In First report on viscosity and plasticity, chapter 1, pages 5–67. Nordemann Publishing, New York, 1939

T = −πI + S S + λ1 S + λ2 S = η1 A1 + η2 A1 Fits experimental data for: N/A

(4. 5a) (4. 5b)

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Giesekus
H. Giesekus. A simple constitutive equation for polymer ﬂuids based on the concept of deformation-dependent tensorial mobility. J. Non-Newton. Fluid Mech., 11(1-2): 69–109, 1982

T = −πI + S S + λS − αλ2 2 S = −µD µ

(4. 6a) (4. 6b)

Fits experimental data for: N/A

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Maxwell, Oldroyd, Burgers Giesekus Phan-Thien–Tanner Johnson–Segalman Johnson–Tevaarwerk

Phan-Thien–Tanner
N. Phan Thien. Non-linear network viscoelastic model. J. Rheol., 22(3): 259–283, 1978 N. Phan Thien and Roger I. Tanner. A new constitutive equation derived from network theory. J. Non-Newton. Fluid Mech., 2(4): 353–365, 1977

T = −πI + S Y S + λS + λξ (DS + SD) = −µD 2 Y = e Fits experimental data for: N/A Josef M´lek a Non-Newtonian ﬂuids

(4. 7a) (4. 7b) (4. 7c)

−ε λ Tr S µ

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Maxwell, Oldroyd, Burgers Giesekus Phan-Thien–Tanner Johnson–Segalman Johnson–Tevaarwerk

Johnson–Segalman
M. W. Johnson and D. Segalman. A model for viscoelastic ﬂuid behavior which allows non-aﬃne deformation. J. Non-Newton. Fluid Mech., 2(3): 255–270, 1977

T = −pI + S (4. 8a) S = 2µD + S (4. 8b) S +λ dS + S (W − aD) + (W − aD) S dt = 2ηD (4. 8c)

Fits experimental data for: spurt
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Johnson–Tevaarwerk
K. L. Johnson and J. L. Tevaarwerk. Shear behaviour of elastohydrodynamic oil ﬁlms. Proc. R. Soc. A-Math. Phys. Eng. Sci., 356(1685): 215–236, 1977

T = −pI + S S S + α sinh = 2µD s0 Fits experimental data for: lubricants

(4. 9a) (4. 9b)

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Kaye–Bernstein–Kearsley–Zapas

Kaye–Bernstein–Kearsley–Zapas
B. Bernstein, E. A. Kearsley, and L. J. Zapas. A study of stress relaxation with ﬁnite strain. Trans. Soc. Rheol., 7(1): 391–410, 1963 I-Jen Chen and D. C. Bogue. Time-dependent stress in polymer melts and review of viscoelastic theory. Trans. Soc. Rheol., 16(1): 59–78, 1972 t

T=
ξ=−∞

∂W −1 ∂W C+ C dξ ∂I ∂II

(5. 1)

Fits experimental data for: polyisobutylene, vulcanised rubber

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