Temperature Behavior of Magnetorheological Fluids

F. ZSCHUNKE*, R. RIVAS, P.O. BRUNN

Friedrich-Alexander University Erlangen-Nuremberg,
Institute of Fluid Mechanics (LSTM), Germany

*Email: zschunke@lstm.uni-erlangen.de
Fax: x49.9131.8529503

Received: 15.10.04, Final version: 14.2.2005

Abstract:
Magnetorheological fluids (MRFs) show a high but reversible rise of the viscosity upon application of an external magnetic field. This effect can be utilized in controllable friction dampers where the MR fluid flows through a gap with a adjustable magnetic field. The change in the magnitude of the magnetic field leads to a change of the viscosity of the fluid which in turn effects the pressure drop in the system. So the damping force can be controlled by the magnitude of the external magnetic field. This energy dissipation leads to a rise of the damper temperature. For designing those dampers it is vital to know the influence of the geometry, which influences the magnetic field strength, as well as the flow properties and the temperature dependence of the magnetorheological effect. An approach to the solution of this problem is shown by using an Arrhenius relationship, where the fluid viscosity is a function of the shear rate, the magnetic field and the temperature. The aim of the here presented research is to show how the fluid behavior can be simply modeled for use in CFD codes to design dampers or other applications.

Zusammenfassung:
Magnetorheologische Flüssigkeiten zeigen eine hohe reversible Änderung des Fließwiderstandes, wenn sie einem Magnetfeld ausgesetzt werden. Dieser Effekt kann in steuerbaren Reibungsdämpfern ausgenutzt werden, bei denen die MR Flüssigkeit durch einen Spalt mit steuerbarem Magnetfeld fließt, wodurch die resultierende Dämpfkraft verändert werden kann. Die so durch Reibung dissipierte Energie führt zu einer mitunter starken Erwärmung des Dämpfers. Um solche Dämpfer auszulegen ist es daher wichtig nicht nur den Geometrieeinfluss zu kennen, der sowohl die magnetische Feldstärke als auch die Strömungseigenschaften verändert, sondern auch die Temperaturabhängigkeit des magnetorheologischen Effekts. Im Folgenden wird ein Model auf der Basis der Arrhenius Beziehung vorgeschlagen, bei dem die Viskosität eine Funktion der Scherrate, des Magnetfeldes und der Temperatur ist. Ziel der hier vorgestellten Untersuchungen ist es ein Flüssigkeitsmodell vorzustellen, dass in CFD Codes implementiert werden kann und das Flüssigkeitsverhalten beschreibt.

Résumé:
Les fluides magnéto-rhéologiques (MRF) présentent une grande augmentation de la viscosité, toutefois réversible, lorsque un champ magnétique externe est appliqué. Cet effet peut être utilisé pour des amortisseurs de friction contrôlable, où le fluide MRF s'écoule à travers un entrefer avec un champ magnétique ajustable. Le changement de l'amplitude du champ magnétique conduit à un changement de la viscosité du fluide qui en retour affecte la perte de pression dans le système. Ainsi la force d'amortissement peut être contrôlée par l'amplitude du champ magnétique externe. Cette dissipation d'énergie entraîne une augmentation de la température de l'amortisseur. Pour mettre au point ces amortisseurs, il est vital de connaître l'influence de la géométrie, qui elle-même influence la force du champ magnétique, ainsi que les propriétés d'écoulement et la dépendance thermique de l'effet magnéto-rhéologique. Une approche vers la solution de ce problème est présentée en utilisant une relation de type Arrhénius, où la viscosité du fluide est une fonction de la vitesse de cisaillement, du champ magnétique et de la température. Le but des travaux présentés ici est de montrer comment le comportement du fluide peut être simplement modélisé pour l'utilisation en codes CFD afin de mettre au point des amortisseurs ou pour d'autres applications.

Key words: magnetorheological fluids, temperature dependence

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

B [mT]	580	510	490	370	240	120	0
C_2 [K]	650.23	700.41	761.02	860.61	940.35	1038.03	1257.17

$\dot{\gamma}$ [1/s]	B [mT] 580	510	490	370	240	120	0
10.80	523.30	355.53	224.50	108.01	49.59	18.62	0.36
13.70	412.36	283.42	203.00	84.77	39.53	14.38	0.29
28.10	202.58	139.81	88.94	41.38	19.72	7.16	0.16
35.60	161.94	112.06	71.42	33.90	16.03	5.78	0.15
45.20	127.17	88.00	56.20	26.65	12.73	4.67	0.11
53.00	108.49	75.02	48.14	22.86	10.94	4.01	0.10
72.80	80.01	55.36	35.67	17.04	8.12	3.01	0.08
92.40	63.54	44.28	28.84	13.65	6.58	2.45	0.07

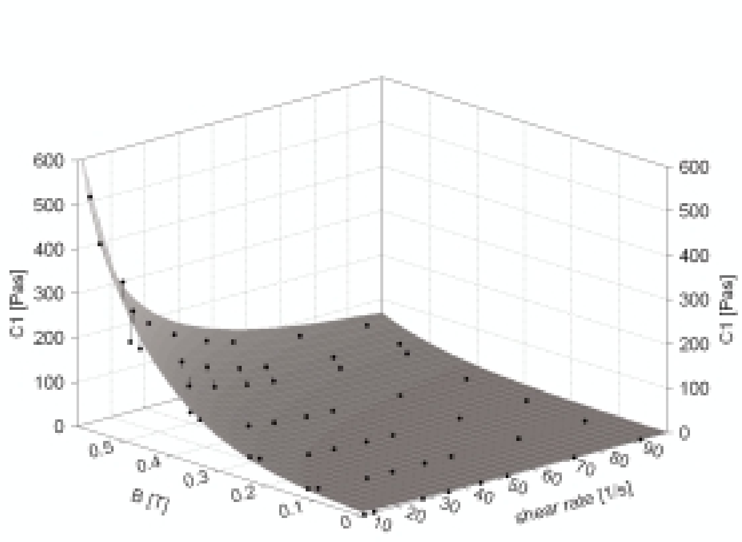

Table 1 (above): Fluid parameter C_2 as a function of the magnetic field B.
Table 2 and Figure 9 (below): Fluid parameter C_1 as a function of the magnetic flux density B and the shear rate.

Where η_m represent the measured viscosities. The calculated results are shown in Table 2. The values illustrate the results already shown in Fig. 4. With rising field strength the relative rise of viscosity decreases due to a magnetic saturation of the suspended particles. In the results for c_1 it can be seen, that c_1 is a function of the shear rate and *B*. In Fig. 9 the results are fitted with a simple function were the units of the shear rate $\dot{\gamma}$ is s^{-1} and the magnetic flux density is given in mT.

$$\ln c_1 = (d + f \ln \gamma + gB) \quad (6)$$

with d = 4.4, f = 0.98 ln s and g = 7.233 1/mT. The proposed fluid model can be expressed through Eq. 7:

$$\eta(\gamma, B, T) = c_1(\gamma, B) e^{C_2(B)/RT} \quad (7)$$

This simple model is capable to show the behavior of the fluid in the shear mode and the flow mode with an transversally applied magnetic field.

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

4 CONCLUSIONS AND OUTLOOK

The temperature effect on the viscosity depending on the shear rate and the magnetic field was measured. It was shown that viscosity of the MR fluid follows the Arrhenius expression with a decreasing temperature influence upon a rise in the applied field strength. This approach has demonstrated that the reason for the temperature effect lies only in the change of viscosity of the matrix fluid. With easy measurements of the matrix oil the temperature dependence of the MR fluid can be predicted. With the measured data it was possible to deploy a simple model for the viscosity as a function of the applied magnetic field strength, the temperature and the shear rate. This model, is capable to be implemented in commercial CFD codes like CFX or Star-CD. Though the model does not describe the anisotropic behavior of the fluid [14], it can be a good tool that can be utilized to predict the resistance of friction dampers using the magnetorheological effect. In those dampers, if carefully designed, the maximum of the magnetic field strength is applied transversally to the direction of the flow. Anisotropic effects don't change the result of the simulation too much, because their contribution to the flow resistance will not be too high. The results show also that it seems to be sufficient to measure the temperature influence on the matrix oil to predict the influence on the MR fluid.

NOTATION

a	[1/mT]	coefficient
b	[-]	coefficient
B	[mT]	magnetic flux density
c_1	[Pa·s]	Arrhenius exponential fluid parameter
c_2	[K]	Arrhenius fluid parameter
c_2^*	[J]	Activation energy
d	[-]	coefficient
E_{12}	[J]	interaction energy
f	[ln s]	coefficient
g	[1/mT]	coefficient
J_p	[mT]	particle polarization
$\|m\|$	[-]	dipole strength
r	[m]	radius
T	[K]	temperature
V	[m³]	volume
ρ	[kg/m³]	density
$\dot{\gamma}$	[s⁻¹]	shear strain rate
τ	[Pa]	shear stress
η	[Pa·s]	viscosity
μ_r	[-]	relative magnetic permeability
μ_o	[H/m]	magnetic field constant
ϕ	[V]	electric potential

REFERENCES

[1] Ashour O: Magnetorheological Fluids: Materials, Characteritaions and Devices, J. Intelligent Mat. Syst. Structures 7 (1996) 123-130.

[2] See H: Mechanisms of magneto- and electro-rheology: recent progress and unresolved issues, Appl. Rheol. 11 (2002) 70-82.

[3] Carlson JD: Electrorheological and Magnetorheological Fluids: A state-of-the-art report, Proceedings od the 9th international Conference on new actuators, Bremen, Germany (2004).

[4] Kordonsky WI: Magnetorheological Fluids and their applications, Materials Technology 8 (1993) 240-242.

[5] Laun HM: Rheometry on magnetorheological fluids, Rheol Acta 35 (1996) 417-432.

[6] Lemaire E: Yield stress and wall effects in magnetic colloidal suspensions, J. Phys D: Appl. Phys 24 (1991) 1473-1477.

[7] Rosenzweig RE:Ferrohydrodynamics, Cambridge University Press, Cambridge, UK (1985).

[8] Vekas L: Physical Properties of Magnetic Fluids and Nanoparticles from Magnetic and Magnetorheological Measurements, J. Colloid Interf. Sci. 231 (2000) 247-254.

[9] Jeo D: Vibration Suppression by controlling an MR Damper, Int. J. Modern Physics B 13 (1999) 2221-2228.

[10] Jolly MR: A model of the behavior of magnetorheological materials, Smart Mater. Struct. 5 (1996) 607-614.

[11] Ly HV: Simulation of Particle Dynamics in Magnetorheological Fluids, J. Computational Physics 155 (1999) 160-177.

[12] Choi SB: A Hysteresis Model of the Field-dependent damping force of a magnetorheological damper, J. Sound Vibration 245 (2001) 375-383.

[13] Barnes HA: An introduction to rheology. Elsevier, Amsterdam (1989).

[14] Kuzhir P, Bossis G, Bashtovoi V: Effect of the orientation of the magnetic field on the flow of a magnetorheological fluid I. plane channel, J. Rheol. 47 (2003) 1373-1384.

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org