Introducing Rheology to Engineering Undergraduates

V.Ilic

University of Western Sydney, Penrith South, Australia

v.ilic@uws.edu.au

Abstract

Rheology is a science of flow and deformation of materials, and is usually a specialist topic reserved for postgraduate studies. It expands on the fundamentals of Applied Mechanics, and deals with phenomena that often are in contradiction to expectations derived from everyday life experiences. Rational explanations rely on advanced mathematical concepts that are usually outside the scope of an undergraduate curriculum. Yet, relatively few students progress to the postgraduate level, and fewer still choose topics from the rheological domain. This deprives majority of students from appreciating the role that rheology plays or could play in the design of devices or in handling of fluids – clearly putting them at a disadvantage.

At the University of Western Sydney, School of Engineering, final year students in Robotics and Mechatronics are offered a series of theses/projects that they could tackle either as a group or individually, depending on their honours status and aspirations. This author offers projects which require knowledge of rheology combined with the understanding of fundamentals of Electrical Engineering involving Magneto-Rheological Fluids or MRFs. Typically, such projects would involve applications of MRFs in the design of vibration dampers and torque transmitters on one hand, and on the other – characterisation of MRFs through establishing a constitutive equations. This paper aims at describing two representative projects in this domain, which is still relatively new in Australia in terms of applications in and by the local industry, and how students advance their knowledge through self-discovery: the most effective way of learning.

Key words: rheology, undergraduate, MRF, learning

Introduction

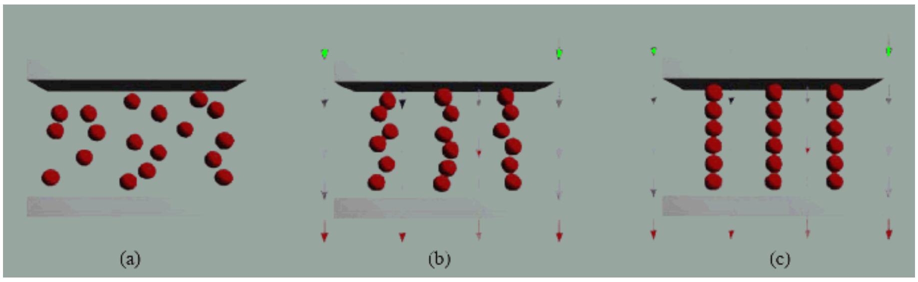
The aim of this paper is to bring to the attention of engineering educators a way of introducing concepts of rheology to undergraduate students. Normally deferred to postgraduate studies, it is a rare university that introduces it to undergraduates. In such cases it is usually an honours stream elective, and usually in the guise of Continuum Mechanics, where analytical foundations are laid for future study of "rheology proper" Notwithstanding the academic rigour required in the formal study, engineering applications abound. It is often the case in everyday engineering practice that problems in rheology have to be tackled ab ovo by a graduate who is not familiar with the subject. The approach taken by this author was to offer to his undergraduate honours students a chance to deal with the unfamiliar, yet relevant to engineering practice – not unlike in a work situation. This paper describes two of the generic types of problems usually on offer – one aimed at fundamentals of the rheological behaviour, while the other aims at the applications in the course of which parameters based on preceding studies are used.

Background

Rheology – the science of "flow and deformation", is well documented in a number of excellent texts such as (Barnes et al 1993), (Wilkinson, 1960), (Tanner, 1985) and (Bird et al. 1983).. Students soon realize what was previously taught (Newtonian fluids) was a special case of much more complex (non-Newtonian) fluids which have new generic names such as bingham, pseudoplastic and dilatant fluids.

It was soon realized that application of electromagnetic fields had an effect of rheological properties of some fluids – that came to be known as electro-rheological fluids, or ERFs,. High voltage gradients produced dramatic change in fluid viscosity in matter of milliseconds – and applications soon followed: dampers, structure stiffeners, couplings for transmission of torque, to name the most common. Hazards associated with high voltage gradients (cc 5KV/mm) limited their widespread use. This had to wait until it was realized that application of magnetic fields could provide the same effect in some fluids (magneto-rheological fluids or MRFs).. In this case only a few volts were necessary to produce the desirable effect via the generated magnetic field and hence had a greater applications potential. The behaviour of both types of fluid was explained on the basis of formation of particle chains in fluid suspensions, which impeded the cross flow of the carrier liquid, Figure 1:

Figure-1: Typical response mechanism of an MR fluid: (a) No applied magnetic field, (b) Magnetic field is applied and (c) ferrous particle chains fully formed (Lord Corporation USA).



Based on this mechanism, various engineering devices could then be made. While applications are still slowly appearing in the market, their application in automotive industry – for design of shock-absorbers (dampers) in cars (Sassi et al. 2005; Shain et al., 2007) and in the active vibration control of engineering structures (bridges and buildings) (e.g. Yoshida et al., 2002; Wang & Gordaninejad, 2002) are most widely used.

At the University of Western Sydney, the final year Mechatronic Engineering students are required to undertake a year-long project that ideally should be the synthesis of what they had learned to date applied to some challenging engineering problem. This author has championed application of "smart" fluids for some of his projects. This paper attempts to provide some reflections on two such recent projects.

Projects

1. A Constitutive Equation for a Magneto-Rheological Fluid (Amal Sari)

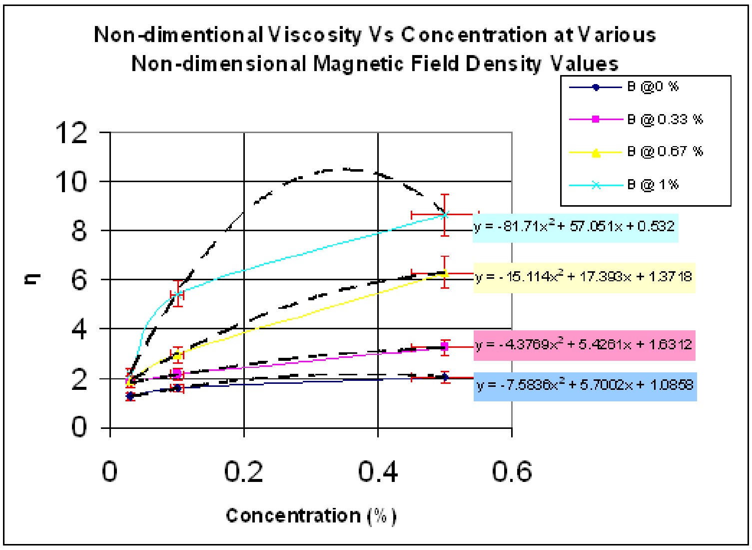
One of the essential design parameters utilizing an MR fluid, is the relationship between its shear viscosity and the strength of the applied magnetic field. This is an experimentally obtained relationship – or a constitutive equation, relating the "cause and effect". The approach adopted in this work was to use the well established relationship for a laminar flow in a duct. The process consisted in timing a flow of fluid through a rectangular duct which had a magnetic field acting across it, and at right angles to the flow of fluid.. The strength of the magnetic field was determined by the magnitude of electric current passing through the coils of an electromagnet. It was therefore possible to relate the magnitude of the electric current with the fluid viscosity using the expression for the laminar flow through a duct. Having done this for a number of values of the electric current through the coil of the electromagnet, it was possible to establish an empirical relationship between the magnetic field strength and the shear viscosity of the MR fluid. Simple curve fitting using readily available linear regression packages, (such as in EXCEL) it was possible to obtain a correlation between the two parameters of interest. While one could stop here, little extra work was done to see how does the concentration of the suspended particles affect the relationship just obtained.

In this project, the student started with "iron dust" collected from a grinding machine operation on a mild steel specimen, mixing it in required concentration with silicone oil and using mortar and pestle produced a suspension that was responding to the presence of a magnetic field – a basic (proto) MR fluid.

The experimental rig consisted of a vertical polycarbonate cylinder 30 mm diameter and 500 mm long with a 1 x 25 mm rectangular duct affixed to the bottom end An electromagnet was designed and made by the student which provided a transverse magnetic field across the 1 mm gap. A calibrated glass beaker was placed underneath, and the rate of filling was recorded Viscosity was then calculated using the standard equation for the laminar flow in a duct, corresponding to the iron particles concentration and the magnetic field strength. A series of curves was then obtained over a range of concentrations, magnetic field strengths, as shown in Figure 3. These were later expressed in non-dimensional form, and a generalized correlation obtained. A qualitative agreement with published data was observed.

Figure 2. Experimental set up

Figure 3. A typical relationship between the experimental variables and attempts to curve fit the experimental data.



2. Design of a smart damper with a magneto-rheological fluid (Varun Kashyap)

Flow of the MR fluid through a narrow space (duct) albeit circular in shape in the case of a cylinder, behaved in exactly the same manner as previously observed. The student designed a cylindrical damper, Figure 4. having a piston with a 1 mm clearance and accommodating a coil that produced magnetic field. Using several control algorithms (sky-hook, ground-hook and fuzzy logic), and assuming a Bingham fluid, the student then produced a SIMULINK model, Figure 5, for parametric assessment of design variables, before building the apparatus.

Workshop drawings were made using AUTOCAD and the system was built using a rotating cam oscillator driven by an electric motor to simulate vibrational input into the damper. MR fluid used was MRF-132DG manufactured by the Lord Corporation, USA.

Figure 4. Cylindrical damper

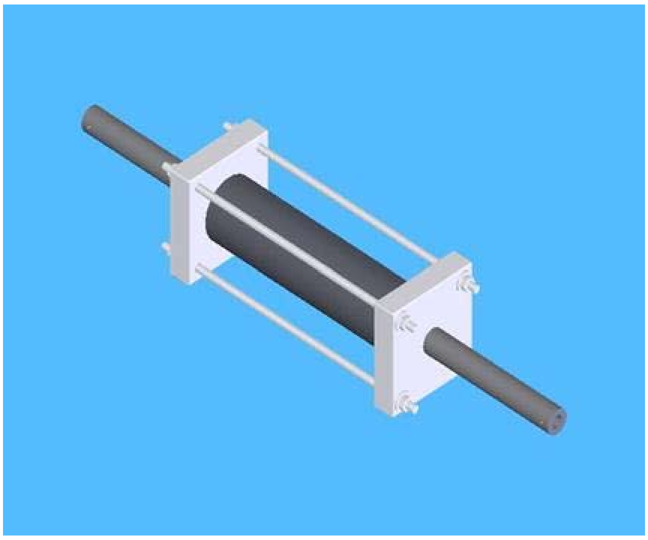
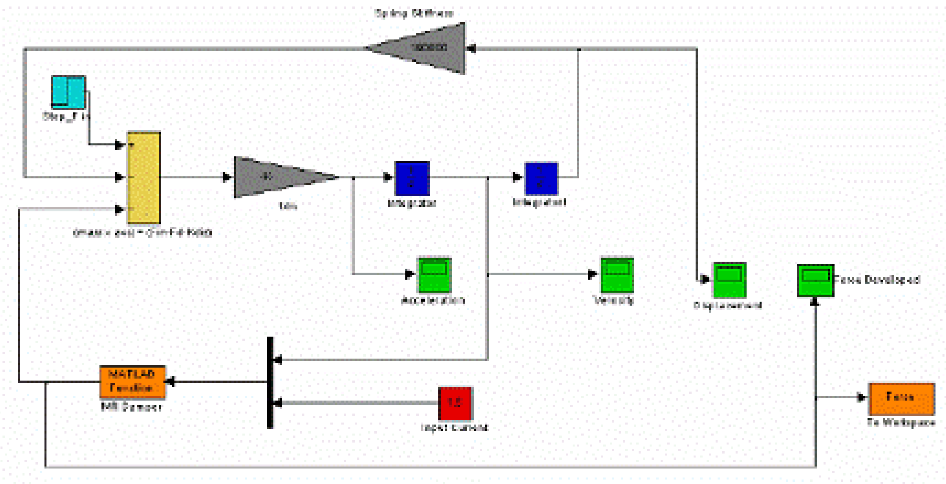


Figure 5. SIMULINK model for a single cylinder damper system



Discussion and pedagogical outcomes

The choice of projects available are determined by individual academic's interests, but within the necessary limitations of an undergraduate course and limited resources available for this type of activity. There are two major considerations that a potential academic supervisor must consider: the ultimate benefit to the student and the ever present budgetary constraints.. The projects were evaluated in terms of student application and the results produced, including working understanding of complex phenomena. From pedagogical point of view the following were some of the principal benefits that students derived from tackling challenges of the kind described.

1. There was a considerable element of learning by self-discovery as students received minimal instruction in Fluid Mechanics, let alone Rheology.
2. Problems given resembled likely challenges to be met in their future work – dealing with unknown and the only way to proceed is to start with the familiar.
3. There was an element of theory, mathematical modeling, machine design, experimentation and data evaluation – a good preparatory work towards a research degree.

4. Students became more confident of their own strengths and acquired a degree of self confidence, self reliance and professional maturity .

Conclusions

Projects of the type described are carried out by honours students who spend on them 28 weeks from the conceptual stage to the report presentation. Introduction of esoteric topics usually reserved for postgraduate studies can be introduced earlier by having students undertake interesting but challenging simple tasks which require quick acquisition of working knowledge of the subject and application towards a practical rnd.

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References

01. Barnes, H.A., Hutton, J.F. and Walters, K. An Introduction to Rheology. Elsevier {1989)
02. Sahin, H., Liu, Y.,Wang, X., Gordaninejad, F. Evrensel, C. and Fuchs, A. Full-scale Mag netorheological Fluid Damper for Heavy Vehicle Rollover. Journal of Intelligent Material Systems and Structures 18, 1161-1166 (2002).
03. Sassi, S., CHerif, K., Mezghani, L., Thomas, M. and Kotrane, A. An Innovative Magneto rhewological Damper for Automotive Suspension: from Design to Experimental Charact erization Smart Mateerials and Structures 14, 811-822 (2005)
04. Tanner, R.I. Engineering Rheology. Oxford University Press (1985)
05. Wang, X. and Gordaninejad, F. Lyapunov-based Control of a Bridge Using Magneto- rheological Fluid Dampers. Journal of Intelligent Material Systems and Structures 13, 415-419 (2002)
06. Wilkinson, W.L. Non-Newtonian Fluids. Pergamon Press, (1960)
07. Yoshida, O., Dyke S.J., Luca, M.G. and Truman, K.Z. Torsional Response Control of Asymmetric Buil ings Using Smart Dampers. 15th ASCE Engineering Mechanics Conference, June 2-5, Columbia University, New York (2002)