Liquid Crystals in Variable Friction Devices

Although the first thermotropic liquid crystalline compound was discovered in 1888 by *Reinitzer*, it was not until almost 80 years later that the phenomenon of an ordered fluid found its first application in electrooptical displays. The ability to switch the orientation of molecules between transparent electrodes is nowadays exploited for displays in wrist watches, pocket calculators, data screens and pocket TV's.[1] The anisotropic physical properties of liquid crystalline materials depend on chemical structure and molecular order. Compounds with rod-shaped molecules can form nematic, different types of smectic (A to I), and also cholesteric including the so-called blue phases, depending on the detailed intermolecular interactions. In the course of the rapid developments in the physics and chemistry of liquid crystals in the last 20 years, it appears to have been overlooked that transitions between such phases, or between the isotropic phase and a liquid crystalline phase, have an enormous potential in mechanical engineering applications. These transitions can be brought about by changes of temperature or pressure. At the Hannover Messe Industrie 1988, a water-cooled brake was presented which exploited the drastic change in effective viscosity which accompanies the transition at 29 °C from a nematic to a smectic B phase[2] in *trans,trans*-4-methoxy-4'-pentylbicyclohexane.[3] The rate of conversion of mechanical to thermal energy in such a brake depends on the appropriate heat-transfer coefficients, the thermal conductivities of the materials involved, and the temperature of the coolant.

At the 12th International Liquid Crystals Confererence held in Freiburg, 15-19 August 1988, some measurements of the change of torque in such a device as it changes its function from a plain bearing to an effective brake were reported.[4] Figure 1 shows schematically a lubricated bearing of given clearance tempered with water. The axle is rotated by a motor with constant speed. The torque M in Nm is the momentum of friction transmitted from the axle to the bearing. Figure 2 gives its dependence on the reciproke temperature for compound 1 as lubricant in the region of mixed friction.

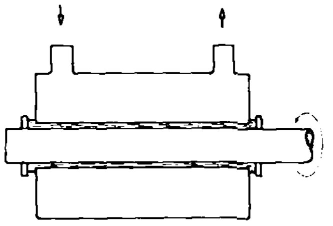

Fig. 1. Scheme of a lubricated axle rotating in a tempered bearing; the form of the lubrication layer corresponds to fully hydrodynamic conditions [5].

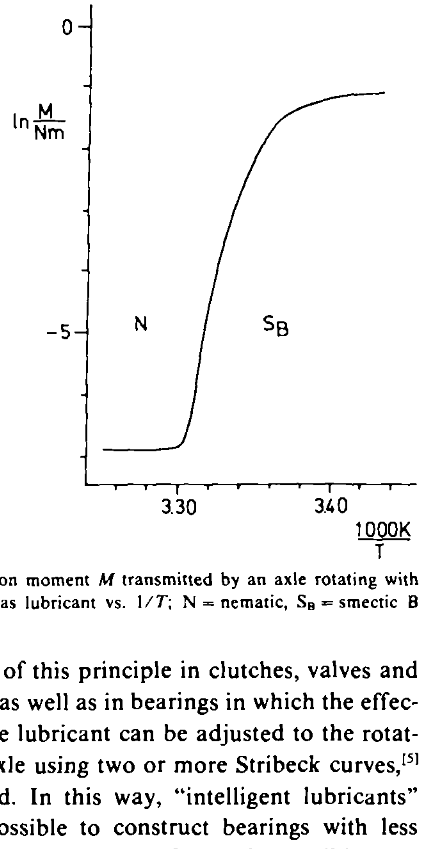

Fig. 2. Plot of the friction moment M transmitted by an axle rotating with constant speed with 1 as lubricant vs. $1/T$; N = nematic, S_B = smectic B phase.

The application of this principle in clutches, valves and hydraulic devices, as well as in bearings in which the effective viscosity of the lubricant can be adjusted to the rotating speed of the axle using two or more Stribeck curves,[5] was also suggested. In this way, "intelligent lubricants" should make it possible to construct bearings with less abrasion and less energy loss. The fast and reversible transition between phases of quite different effective viscosity also suggests new ways of designing mechanical components.

The basis for the understanding of friction in bearings under pure hydrodynamic conditions is given by the Reynold's differential equation. Although this has not been completely solved, the behavior is adequately understood for the case of isotropic lubricants, also including the case of mixed friction.[5] The description of friction in ordered fluids, taking into account the coefficients in the viscosity tensor (5 independent coefficients for the nematic phase, and many more for a smectic phase depending on its symmetry) is a formidable task. The measurements reported demonstrate that the orientation at the surfaces of the materials making up the device has a great influence on the frictional torque.

The phase transition is most easily brought about by changes of temperature. The use of Peltier elements seems to be of particular interest for low power devices. For many types of devices it would be useful to have high viscosities at high temperatures and low viscosities at low temperatures, i.e. the opposite of the usual situation. Leaving aside the possibility in principle of using liquid crystals with re-entrant phases,[6] there is no solution to this problem under isobaric conditions. In these cases phase transitions induced by changes of pressure are a possibility. At constant temperature the more highly ordered phase appears at higher pressure.[7] Thus, changes in effective viscosity can be expected at pressures much lower than those used with transmission fluids and oils, e.g. in gear-transmissions.[8] Unfortunately, kinetic data on transitions between the isotropic phase and a smectic phase, or between a nematic phase and a smectic phase, are not yet available. From isobaric microscopic observations it can be estimated that in compounds such as 4,4′-dialkylbiphenyls the molecular rearrangement will take place within a small fraction of a second at room temperature.

To be applicable in engineering many tribological conditions must be fulfilled. Obviously the compounds tested so far wet metals very well. There are many compounds of low molecular weight that are apparently resistant to hydrolysis and oxidation by air at not too high temperatures. A lucky circumstance is the fact that many stable and relatively easily synthesized compounds have an S_B phase, a highly ordered phase within the smectic layers. The occurrence of such a phase was undesirable in compounds synthesized for electrooptical displays. One can predict that, because of the low molecular weight, the resistance to molecular cleavage by shear forces should be good. The role of cavitation forces in highly stressed layers needs to be investigated by long-term tests. The point to be careful about seems to be the presence of organic impurities in the friction layer, which can cause a shift of the transition temperature.

R. Eidenschink
Nematel, Mainz (FRG)

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Conference Reports

Liquid Crystals Centenary

The 12th International Liquid Crystals Conference, held in Freiburg, FRG, on 15-19 August 1988, was attended by over 700 scientists from 31 countries; it is especially noteworthy that these included delegates from the German Democratic Republic and other eastern block countries. The conference, which was sponsored this time by the Deutsche Bunsen-Gesellschaft für Physikalische Chemie, is one of a series that began in 1965 in Kent, Ohio, USA; it is held bienially, the preceding one having been in Berkeley, California. One of the reasons for holding this year's conference in the Federal Republic of Germany is that the discovery of liquid crystals by *Friedrich Reinitzer* took place there 100 years ago. German scientists in Karlsruhe, Freiburg and Halle/Saale became closely involved in further studies of this fourth state of aggregation of matter, whose existence did not at first go unchallenged.

The scientific program of the conference included eight plenary lectures (45 min), 17 invited lectures (30 min), 58 short contributions (15 min), and 420 poster presentations. Apart from the plenary lectures, the meeting was divided into two parallel sessions covering the following main topics:

1. Synthesis and molecular properties (SY)
2. Polymer liquid crystals (PO)
3. Lyotropic liquid crystals (LY)
4. Chiral liquid crystals, blue phases (CH)
5. Ferroelectric liquid crystals (FE)
6. Applications (AP)
7. Surfaces and interfaces (SU)
8. Phase structure and transitions (PH)
9. Molecular dynamics and molecular theory (DY)
10. Instabilities, defects and fluctuations (IN)
11. Nonlinear optics in liquid crystals (NO)

During the course of the twelve conferences held since 1965 the number of scientific contributions has grown in an approximately linear fashion (Fig. 1). The Scientific