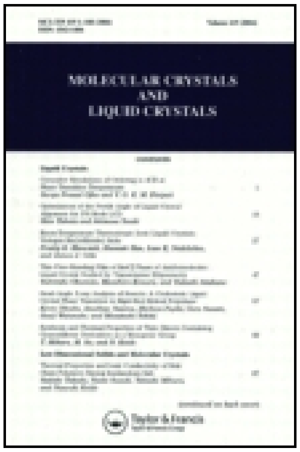

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Reduction of Friction Through Presmectic Lubricants

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REDUCTION OF FRICTION THROUGH PRESMECTIC LUBRICANTS

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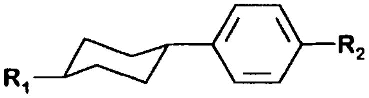
Abstract Surprisingly low friction losses can be realized in plain bearings lubricated with different 4-(trans-4-alkylcyclohexyl)-alkylbenzenes. Possible reasons for this behavior at temperatures far above the regime of ordered fluid phases are discussed. Limitations of application are outlined.

INTRODUCTION

The economic damage caused by friction and wear in engine bearings is a main topic of intense interdisciplinary research. Thermotropic liquid crystals have been discussed as lubricants for some time. Thus low values of the coefficient of friction f in slide bearings obviously working in the hydrodynamic regime with thermotropic nematic[1,2] or smectic A[3,4] phases have been reported. The fast and reversible transitions from a low viscous nematic or isotropic phase to a highly viscous smectic phase has been suggested as a possibility to work with two Stribeck curves minimizing the regime of disadvantageous boundary friction and mixed friction at low speeds and exploiting the low inner friction in the hydrodynamic regime[5]. Here it is shown that low values of f can be obtained in very slowly sliding bearings lubricated with mesogenic compounds which at room temperature under normal pressure are low viscous isotropic liquids.

EXPERIMENTAL PART

Tab. 1 shows some relevant properties of the compounds 1 to 3 used as lubricants.



The gaschromatograpic purity of all compounds was ≥ 99,7 %.

	R_1	R_2	Transitions	Viscosity
1	C_7H_{15}	C_5H_{11}	C 290 S_B 291 I	25
2	C_7H_{15}	C_3H_7	C 275 S_B 279 N 291 I	20
3	C_3H_7	C_2H_5	C* 276 S_B (238) I	4

C = crystalline, S_B = smectic B, N = nematic, I = isotropic

TABLE 1 Temperatures of phase transitions (K) and viscosities (mPas, 298 K) of some 4-(trans-4-alkylcyclohexyl)-alkylbenzenes at normal pressure, *crystal phase supercoolable to 223 K.

Brand new spherical plain bearings GE30ES (SKF Schweinfurt, Steel 100CR6, sliding diameter d 40.7 mm, sliding width b 15 mm) were cleaned with acetone in an ultrasound bath, dried and then wetted with compounds 1 to 3. After 15 min. of a run in operation under a load of 30 MPa in the apparatus described below the bearings were cleaned and wetted again. The average surface roughness R_Z[6] then was at 1 μm. The friction coefficients f were determined by a common apparatus[7] with a tensile steel mounting, a gear motor, a hydraulic loading device and piezoelectric cells for the measurement of normal force and friction force. The temperature T of the bearing was measured by a thermoelement in an orifice in the mounting at a distance 3.6 mm from the slide contact.

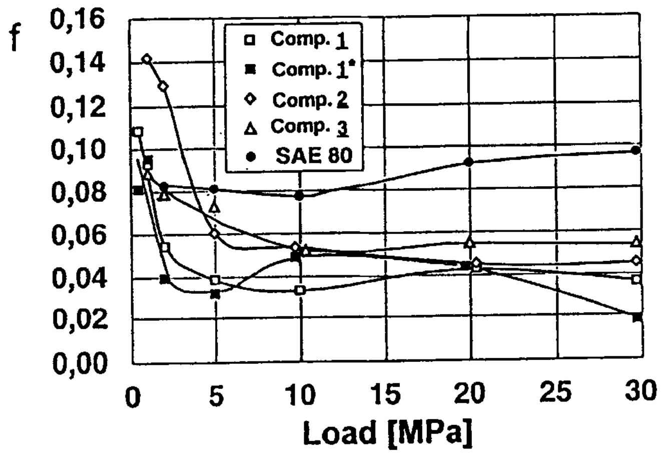


FIGURE 1 Friction coefficient f vs. load of a spherical plain bearing GE30ES with different lubricants, sliding speed 0.010 - 0.012 m/s, *different bearing.

Fig. 1 shows the dependence of f (friction force over normal force) vs. load p (normal force per projected bearing area bd) measured at a *uniform* sliding velocity v between 0,01 and 0,012 m/s. Each curve was taken with a new bearing. Starting at the lowest load each point of measurement was recorded after 30 min. to accomplish stable values of f and T. The curve obtained with the commercial oil ARAL EP SAE 80 W (viscosity at 298 K 130 mPas) is also shown. T expectedly rose with load imposed. At 32 MPa temperature leveled out at 312 K for 1, 309 K for 2 and 315 K for 3 (ambient temperature 293 to 296 K).

DISCUSSION

Fig. 2 shows a classical Stribeck curve[8] of an isothermally operated slide bearing. The dependence of f on bearing speed v, and dynamic viscosity η can be roughly divided into the regimes of boundary, mixed and hydrodynamic friction. Because of the very low speed chosen one would have expected all fluids - including the relatively high viscous SAE 80 W - to operate in the boundary regime in which f is reasonably independent of load and typically ranges between 0.08 and 0.12[9]. In this regime the fraction of load

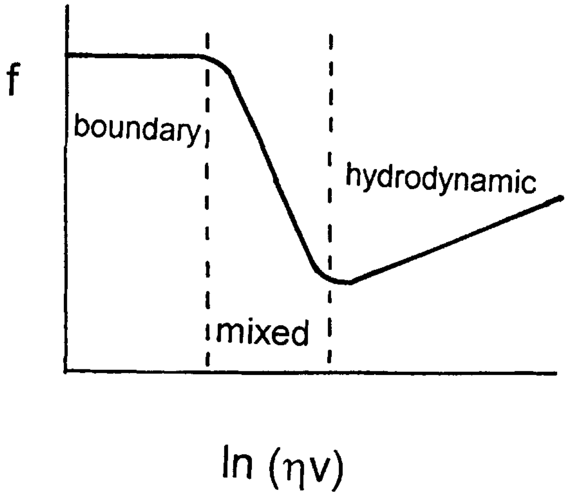


FIGURE 2 Empirical Stribeck curve, friction coefficient f in plain journal bearings, logarithmic function of dynamic viscosity η and sliding speed s.

borne by the aspireties on the surfaces of the bearing is very high whereas the influence of microscopic areas having build up a hydrodynamic film can be neglected.
Keeping to this picture the observed decrease of f is explicable by the induction of a high viscous layer preventing a distinct ratio of the asperities from direct contact. In the case of compounds 1 - 3 the phase transition to a smectic B phase is an obvious explanation. As the pressure dependence of the transition temperature from isotrop or nematic to smectic B for this class of compound is only some 0.3 K/MPa[10] the high shifts of temperature (e.g. $\geq$ 77 K in case of 3) cannot be reasoned by the static pressure imposed. The influence of dynamic pressure is negligible because of the low speed. It was suggested to extend Clausius' equation by a term containing both a pressure normal to the surface being proportional to shear stress and the shift of viscosity between the phases involved[11]. However, the physical relevance of such a pressure has been questioned. The theoretically well founded concept of a shear induced ordering transition in thin films between molecularily smooth solid surfaces[12] provides another possibility of explanation. According to this, friction coefficients are very low when layers of n-alkanes are oriented with their short molecular axis normal to the sliding direction. For technical metal surfaces a concept has to be supplied how a reasonable ratio of the irregularly shaped asperities - how elastic[9] they maybe - should adopt a few molecules' distance simultaneously. The compulsion to form ordered layers under shear may also be seen in a more general way in relation to the principle of maximum energy flow[13] in which the exchange of energy (in this case by collision) between the molecules involved is treated in analogy to Poynting's theorem. This is in line with an old theory[14] that connect viscosity with an exchange frequency. This is highest in the direction normal to the sliding surface if the anisotropic molecules are aligned described above. The recent finding[15] that in a twin-disk-machine lubricated with a compound of disk-formed molecules (discotic below 263 K) at 333 K f becomes unmeasurably small in certain regions of Hertzian contact stress, speed and slip can be seen in accordance with this view.

The applicability of the presmectic compounds 1 - 3 has been found to depend on several conditions. Low values of f are difficult to reach with bearings of high surface roughness. The combination of high speed and high load also turned out to be disadvantageous whereas in fast oscillating low loaded textile machines an important industrial application could be accomplished[16] with a considerable reduction of wear. In slide bearings the effect described was generally found to depend very much on the kind of contact. It increased from point over line to area contact. In a roller bearing a separating film could be detected at comparatively low speed. This advantage could not be maintained at high loads. However, it was found that 1 shows an increase of shear strength with pressure distinctly lower than most modern oils.

OUTLOOK

The application of thermotropic liquid crystal lubricants is still at its beginning. The fast and reversible induction of highly ordered layers in bearings has the perspective of reduction of wear and conservation of energy. Materials must meet the demands of very high thermal and chemical stability. Because no polymer additives are needed to bring about high viscosity mechanochemical degradation of the fluids described is expected to be low. Basic experiments are still missing. Of particular interest is the kinetic of the formation process of highly ordered layers.

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