Lubricity of Water Based Coolants (WBC) for Screw-Spindle-Pumps

Comparison and Modification of Test Methods for the Evaluation of Lubricity

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Abstract

There exist different methods for the evaluation of the lubricity of greases, oils and other fluids. Mostly the lubricants are optimized for special applications. E.g. coolants for machine tools are optimized for the cutting or grinding process with high specific loads but not for the pumps that must handle it. Also many test methods for the lubricants operate with high specific loads and material combinations that are not representative for conditions inside the pumps.

The Brugger-method following DIN standard 51347 is one example for such test which allows the evaluation of viscid oils concerning their lubricity. There exist a standardized installation, a test-cycle and standardized test-samples. For the evaluation of water-based coolants, this method is not suitable. This article focuses on modifications of above test method in order to achieve meaningful results also for water based coolants. In this juncture there were accommodated the operational demands of a certain screw-spindle-pump-type.

1 Working Principle of Screw-Spindle-Pumps and their Applications

Screw-spindle-pumps belong to the group of rotating positive displacement pumps. During the past, different modifications have been developed, which can be a single- or double-flow-type. Depending on the application the pumps have one (eccentric screw pump) up to 5 spindles [1]. The applications reach from ropy fluids with solid particles (eccentric screw pump) over bad lubricating fluids (e.g. two spindles for oil production) to the pumping of lubricating fluids (three to five spindles) [2]. Multi-phase-media in the field of oil production (water-gas-oil-sand-mix) lead to an ambitious tribological challenge [3]. Different manufacturer report for general applications maximum pressures up to 310 bar [4], for special cases up to 400 bar [2], and maximum volume flows up to 5000 m³/h [5].

This article only focuses on screw-spindle-pumps with three spindles, which are used mainly for the pumping of coolant for machine tools. The pressures for these applications typically stay between 5 and 150 bar and volume flow ranges from 10 to 900 l/min [6]. Typical viscosities are between 1 mm²/s for water based coolants and 40 mm²/s for grinding oils. Higher viscosities are possible but uncommon. Depending on the machined material and used tools, there also appear extreme tribologically challenging conditions. Although the fluid is filtered, the solid content often is far away from oil hydraulic's conditions, especially concerning grinding processes with abrasive particles from carbide metal, SiC, Al_2O_3, CBN, diamond or other ceramics.

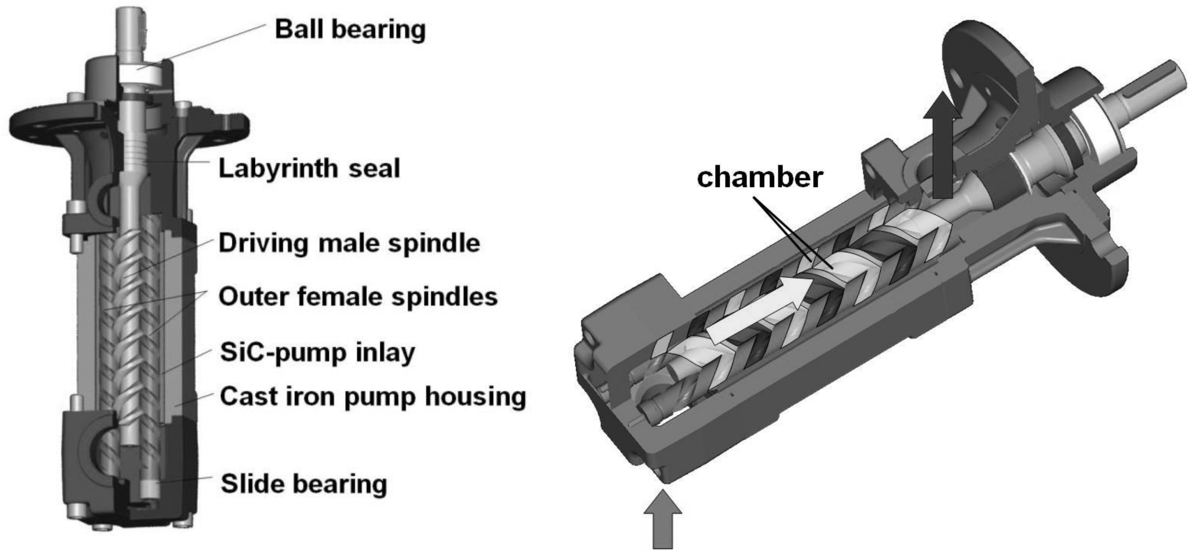

Fig. 1: Principle and function of a screw spindle pump with three spindles (manufacturer: Brinkmann Pumps)

Screw-spindle-pumps for machine tools usually have only one exterior roller bearing, **Fig. 1**. All other bearing functions inside are realized by interaction of the pumped fluid, the housing and the spindles using hydrostatic or hydrodynamic principles likewise journal bearings. The pump needs no synchronizing gear between its spindles. In order to stand the tribological aspects of the application, highly wear resistant materials are necessary on the one hand. Therefore hardened and optionally coated spindles are used and the housing is made of Siliconcarbide (SiC). On the other hand the pumped fluid must have a minimum lubricity in order to separate tribological partners.

The principle of this pump is based on the creation of chambers (in **Fig. 1** marked alternately highlighted and dark) that are axially positioned one behind the other. These chambers are built by the tooth spaces, which move axially through the housing when the shaft is turned. These chambers lead to an inner multi-stage design. The volumetric efficiency depends significantly on the number of chambers and the geometry of internal gaps between the chambers.

2 Aspects of Fluid Lubricity in Screw-Spindle-Pumps and corresponding Test Methods

Taking a look on the principle of the shown screw spindle pump (**Fig. 1**), there can be detected several places, where the lubricity of the fluid could influence the pump's operation (**Fig. 2**):

1) Radial forces at the outer diameter of the female spindles (high)
2) Axial forces at the suction end of the female spindles (high)
3) Torque forces between spindles each other (normally low)
4) Radial forces at the outer diameter of male spindle (normally zero)
5) Radial forces at the outer diameter of the labyrinth seal (normally zero)

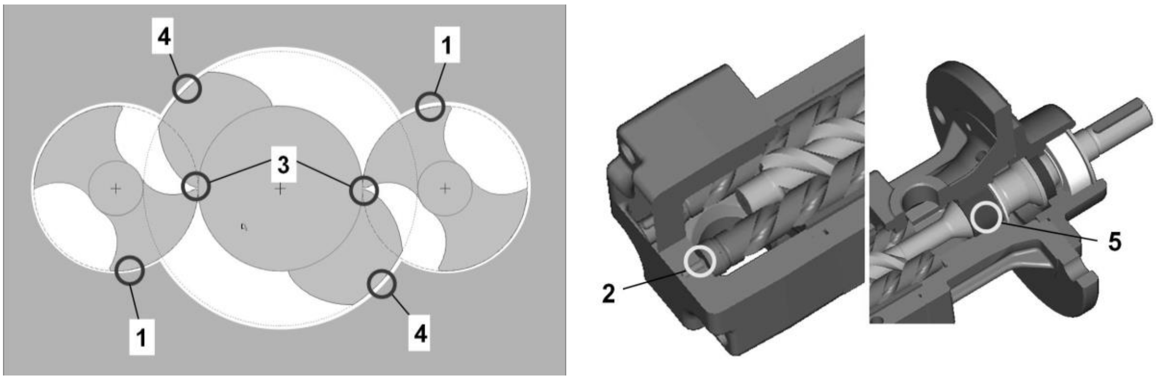

Fig. 2: Places where lubricity can influence the pump's operation; left: cross section of spindle geometry; right: parts shown in a 3-d-model

As a consequence the question comes up, which method would be useful to investigate the lubricity of fluids that are pumped with a screw-spindle-pump. First of all it is important to be aware that the term "lubricity" is not only a property of the fluid. In general a mechanical device contains tribological systems with certain conditions, e.g.:

1) Tribological partner no. 1 with its properties (material, hardness, surface roughness…)
2) Medium in between with its properties (fluid-type, viscosity, additives…)
3) Dirt particles in medium with its properties (material, size, hardness…)
4) Tribological partner no. 2 with its properties (material, hardness, surface roughness…)
5) Temperature (average, local contact…)
6) Specific load (tension, relative speed…)

More general information about tribological systems and lubricity can be found in [7-14]. Against this background it is understandable that lubrication tests are very specific. To give an example: a technical printing of a manufacturer of lubricants shows 28 different methods for the evaluation of lubricants [15], which is just a selection. Many of these tests are designed for grease. But screw-spindle-pumps for machine tools usually handle fluids like the following:

1) Mineral oil (usually no problems)
2) Water-based coolant
    a. Emulsion with oil content (usually no problems, except too low concentration)
    b. Synthetic coolant without oil (lubricity for pump operation could be critical)

Such coolants normally are designed for cutting processes with high specific load and high local temperatures at the micro contacts. Furthermore sometimes ingredients need a special minimum temperature to be effective.

Some methods that would be suitable for fluids are:

1) Ball / pin on disk test [16]
2) Brugger test [17]
3) Reichert test [15,18]
4) Shell 4 ball test [19-21]
5) Timken test [22,23]
6) Translatory oszillating test [24,25]

3 Modifying the Test Method and Corresponding Results

The brugger method is only one of several possibilities but it can be realized by a small simple test rig, **Fig. 3**. Cylinder 1 is pressed on cylinder 2 with a certain force, while cylinder 2 is rotating. The two cylinders are orientated with an angle of 90° to each other. After the test there will be an elliptical wear mark in cylinder 1, which can be measured, **Fig. 4**. The standard test-conditions according to [17] are a force of 400 N, a velocity of 1,2 m/s and a test time of 30 s. Additionally the fluid is not in a tank, it only is dumped onto cylinder 2 and only adhered fluid is in progress. Usually the cylinders are made of steel.

Unfortunately the first tests with such parameters had been shattering. Comparing two very different water-based fluids it was impossible to find significant differences in the test-results (wear marks). It could be concluded that the test conditions had to be modified and it was found:

1) The material of cylinder 1 was modified corresponding to pump components
2) The material of cylinder 2 was modified corresponding to pump components
3) The surface of cylinder 2 was prepared with a special diamond tool insuring a defined surface roughness on the chosen material
4) The fluid was not only dumped but provided by a tank, see **Fig. 3**
5) The force was reduced according to worse lubricity of water-based coolants. Also differences could be seen more clearly.
6) Not only the wear mark but also the friction (motor current) have been measured during the test, leading to characteristic curves
7) Deionized water was used as reference before every test

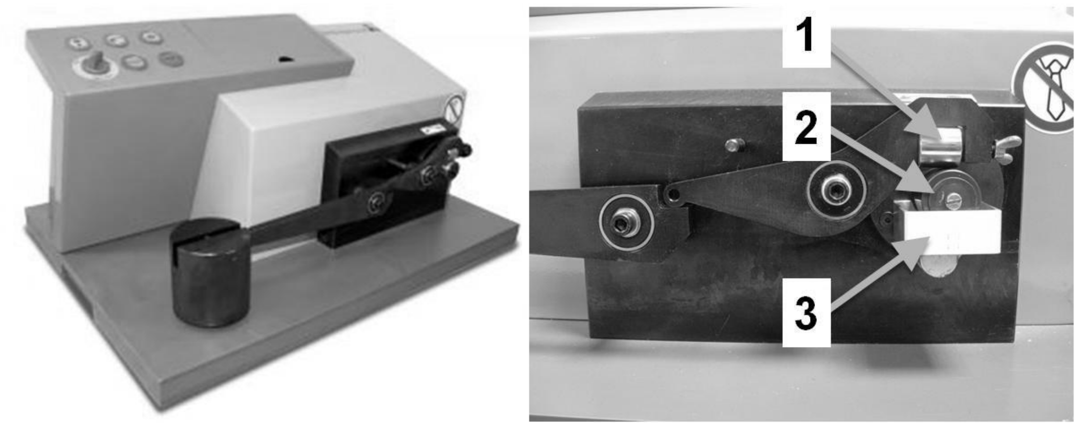

Fig. 3: Brugger test-rig; 1 stationary cylinder, 2 rotating cylinder, 3 fluid tank

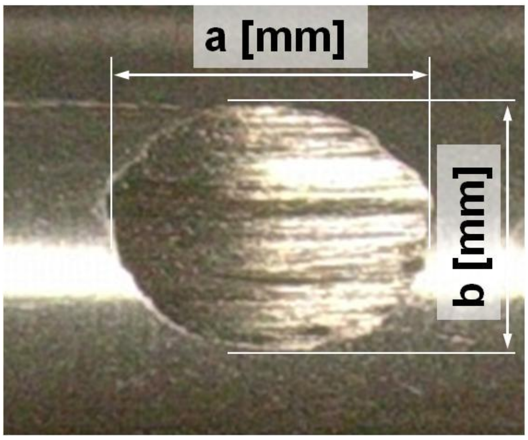

Fig. 4: Typical, elliptical wear mark in cylinder 1: a and b are usually few millimeters. Wear mark area A is calculated by $A = \Pi/4*a*b$

Like mentioned in the DIN-standard it was necessary to do at least 2 or 3 tests with the same fluid in order to exclude outlier. Only little differences like touching the samples with fingers, using tap water instead of deionized water or wrong surface treatment of cylinder 2 led to different results. This also brings out the sensitivity of this method.

4 Test Results

In order to get experience, there had been tested totally different types of coolants:

1) Deionized water (fluid A)
2) Synthetic water based coolant with bad lubricity (fluid B)
3) Synthetic water based coolant with lubricating additives (fluid C)
4) Water based coolant with mineral oil content (emulsion) (fluid D)

The diagrams show interesting results, **Fig. 5**.

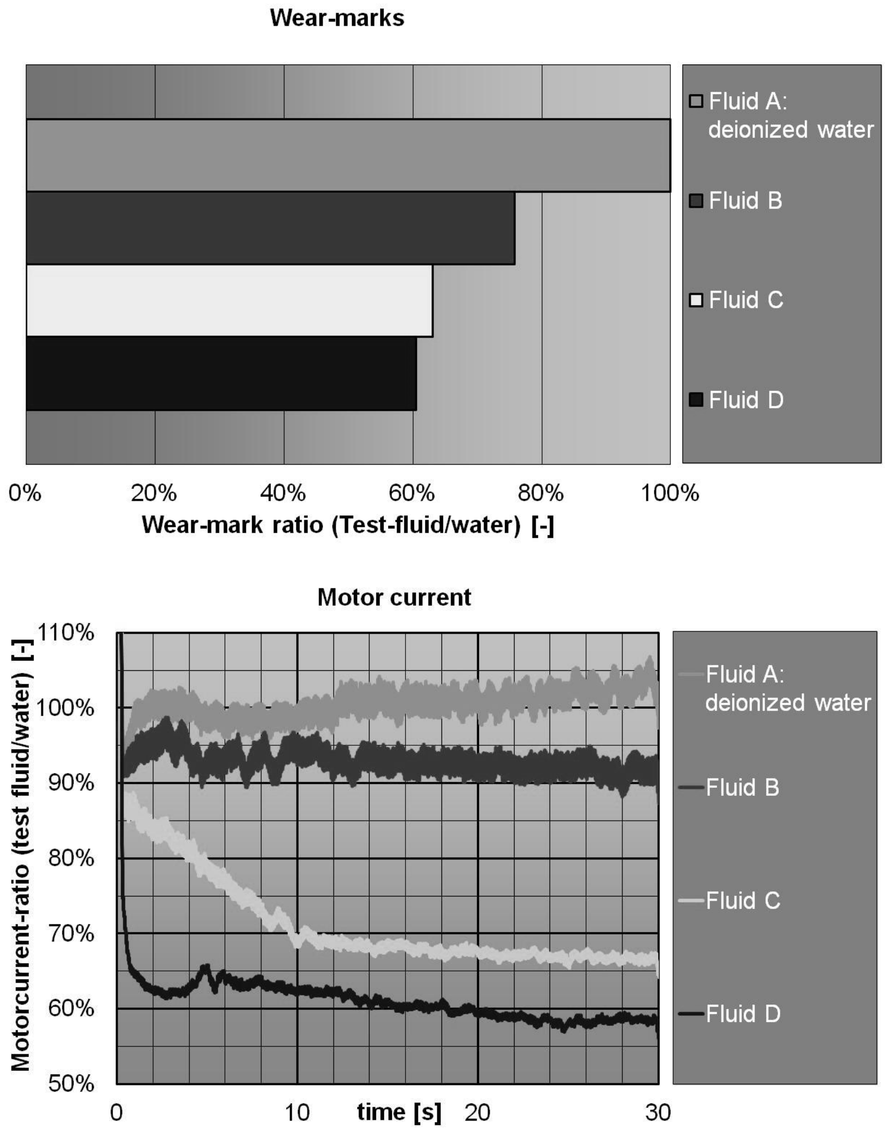

Fig. 5: Comparison of test results

Compared to the beginning where the differences could not be seen clearly, we now achieve results that allow quantifying the fluids’ behavior: Pure water has the worst properties. This was predictable but also shows the plausibility of the method and the chosen parameters.
Fluid D with a content of mineral oil has the best lubricity. It was expectable that emulsion with oil content would be quite good, but we now have the result, that the other fluids (B+C) have quite different properties. On the one hand the motor current shows the differences more intensively compared to the wear traces; on the other hand it becomes obvious that fluid D is working well very quickly.
Also fluids without oil can have good properties (fluid C) but this fluid for example needs some time to activate the lubricating additives. The course of the motor-current-diagram is not randomly. Repeating the test always leads to similar diagrams and seems to be typical for this kind of fluid.
There are also coolants in industrial use that show a quite bad lubricity under the chosen test conditions (fluid B). In these cases it can be necessary to realize tests with real pump operation.
Additionally there have been done examinations with 6 different kinds of material combinations [26]:

1) Ceramic / hardened steel
2) Ceramic / cast iron
3) Ceramic / cast iron (special hardening process)
4) Hardened steel / hardened steel
5) Hardened steel / cast iron
6) Hardened steel / cast iron (special hardening process)

It was experienced that combination 4 caused unstable conditions probably due to fretting effects at the material surfaces. The other five combinations partially caused different results but showed likewise tendencies comparing the fluids. Especially water always produced the worst data.
Also different concentrations of some coolants had been tested. An increase from 5% to 10% concentration of a synthetic fluid E, see **Fig. 6**, improved lubricity significantly but an increase from 10% to 15% concentration revealed no significant improvement.
In summary this test method allows a comparison of different water based coolant types concerning many aspects of their practical application for certain test conditions.

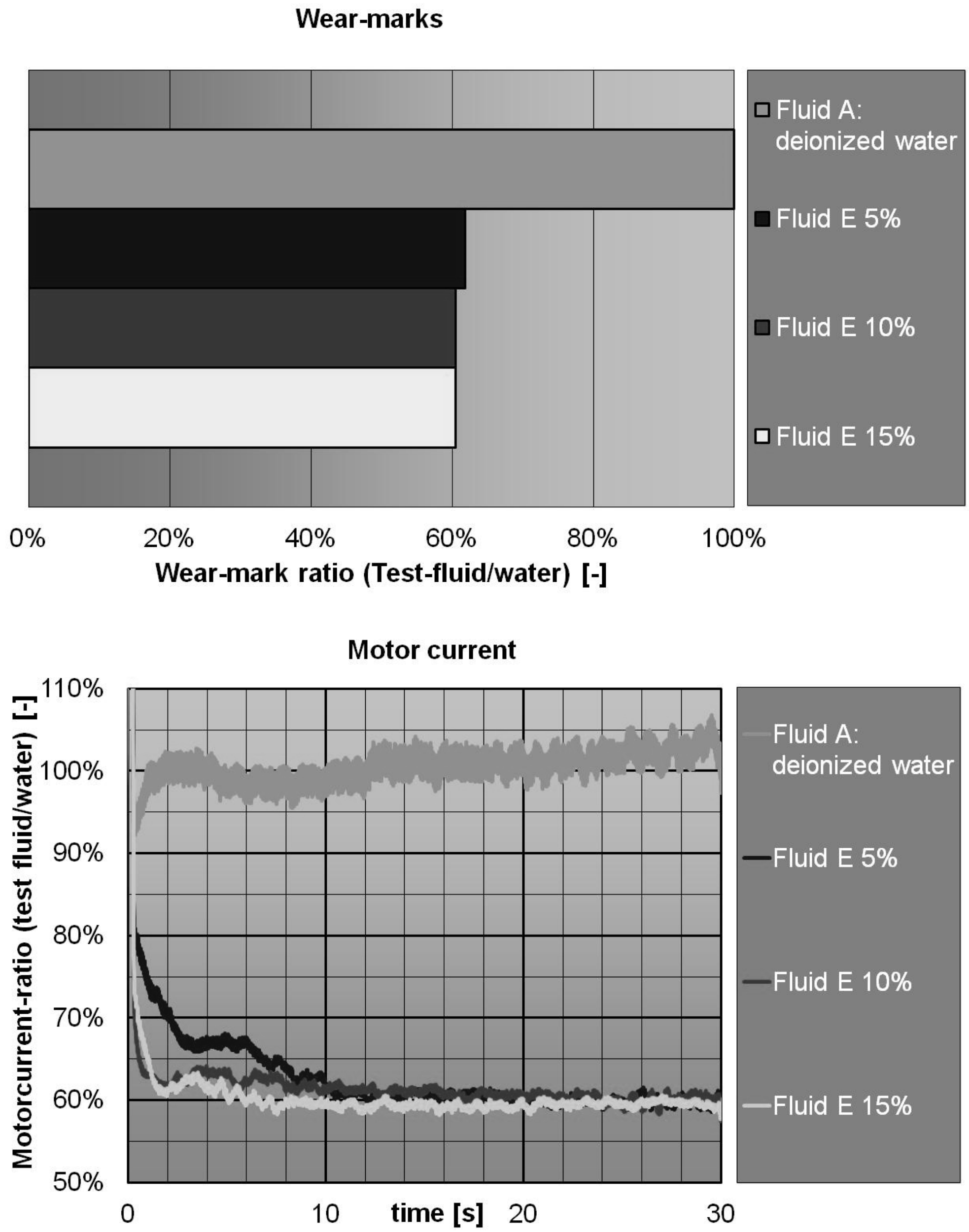

Fig. 6: Influence of fluid E's concentration

6 Assignability to Real Pump Operation

As the test conditions are very specific this test cannot substitute all real pump tests. But it helps to find out critical coolants. Practical tests showed that the pump is less sensitive to the lubricity than expected. At least the wear inside the pump was so little that it could hardly be measured after several hundred hours of testing and therefore it was difficult to distinguish between the effects of coolant's lubricity.

On the other hand it was experienced that fluid B caused noisy operation under certain conditions (low concentration, high pressure), which corresponds to the bad lubricity of this coolant. It could also be shown that choosing a special pump option allowed a silent pump operation even under above critical conditions. This option contains a so called “axial thrust compensation”, which means that the axial forces of the female spindles are taken by hydrostatic slide bearing instead of a hydrodynamic one. Therefore mixed friction can be avoided at least at this place.

6 Summary and Outlook

The investigations showed that the Brugger-method according to DIN 51347 can be modified to examine special fluids like water-based coolants and specific material combinations. This can also be seen as some kind of customizing standard-methods. Playing with the testing parameters interesting results about the lubricity of water-based coolants for the operation in screw spindle pumps were found. Different coolant types had been compared with deionized water and with each other. Different properties could be seen clearly and also the influence of the concentration.

Although this method helps to find critical fluids, it cannot substitute real pump-tests completely because there are different (and in detail other) operating conditions inside the pump at the same time. Finally the pump was less sensitive to lubricity than expected.

All tests had been done with clean coolants. Under real operation conditions often abrasive sediments are encountered inside the fluid. This could lead to interdependency with the lubricity and as a consequence this would be interesting to investigate in future.

7 Literature

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