A CONSTANT TEMPERATURE FZG TEST FOR OPEN GEAR LUBRICANTS

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ABSTRACT
The 12-stage FZG test (A/8,33/90) was originally developed to determine scuffing load capacity of engine oils [1]. During each load stage, the test is started at the same initial sump temperature. Heat of friction generated during a load stage results in a temperature increase of the lubricant. Final sump temperatures as high as 140 °C are often reached after the final load stage (Load Stage 12).

A modified version of the test, (A/2,76/50) is used for laboratory determination of open gear grease performance [2]. In open gear lubrication, typical gear operating temperatures are in the range 50°C–80°C. Test temperatures higher than this may give rise to different wear characteristics than would be found under typical operating conditions. It would therefore be of practical interest to have a laboratory-based means to determine the temperature-dependent characteristics of an open gear lubricant.

A compact heat exchanger was designed, built and inserted in the FZG test bed. By manipulating the flowrate of an external cooling medium, the temperature of the test fluid in the sump can be maintained at a desired temperature.

Results for four representative open gear lubricants were obtained using the constant temperature test and compared with results obtained with the conventional test. These results indicated that the new test can discern between samples that perform similarly during the conventional test.

INTRODUCTION
A total of four open gear lubricants were selected. The performance of these products was quantified by monitoring the following:

(i) Mass change per load stage
(ii) Final sump temperature achieved per load change for the uncontrolled case.
(iii) Exact measurement of heat removed in order to maintain a chosen operating temperature for the controlled case.

NOMENCLATURE
\[ \rho \] = Density \ (kg/m\(^3\))
\[ F \] = Volumetric flow-rate \ (m\(^3\)/s)
\[ C_p \] = Heat capacity \ (kJ/kg°C)
\[ T \] = Temperature \ (°C)
\[ Q \] = Rate of energy transferred \ (kW)
\[ V \] = Volume \ (m\(^3\))
\[ E \] = Energy \ (kJ)

Subscripts:
\( c \) = coolant
\( l \) = lubricant
\( e \) = environment
\( f \) = friction

THEORETICAL BASIS FOR THE CONSTANT TEMPERATURE TEST
Assuming that, for a fluid, enthalpy can be substituted for energy, an enthalpy balance over the lubricant in the sump gives:

\[ \rho F_c C_p (T_e - T_{e,m}) + Q_f - Q_e = \frac{d}{dt}(\rho V_c C_p T_e) \]  \hspace{1cm} (1)

Heat generated due to friction is a fraction of the energy transferred to the gears via the motor drive. In a similar manner, an enthalpy balance over the cooling fluid passing through the cooling coil gives:

\[ \rho F_c C_p (T_e - T_{e,m}) + Q_e = \frac{d}{dt}(\rho V_c C_p T_e) \]  \hspace{1cm} (2)

Combining equations (1) and (2) and rearranging to solve for heat generated due to friction, results in:

\[ Q_f = \rho F_c C_p (T_e - T_{e,m}) + \frac{d}{dt}(\rho V_c C_p T_e) + \rho F_c C_p (T_m - T_{m,m}) + \frac{d}{dt}(\rho V_c C_p T_m) + Q_e \]  \hspace{1cm} (3)
In a drip lubricated system, the first term in equation (3) above is negligibly small due to the very low circulation rate of lubricant, while the accumulation term for the coolant is also negligible due to the small volume of the cooling coil relative to the volumetric flow-rate of coolant passing through. Lastly, it may be assumed that heat losses to the environment are negligible. Equation (3) then simplifies to:

\[ Q_f = \rho_f C_p (T_{cw} - T_o) + \frac{d}{dt}(\rho V C_p T) \]  

Integrating equation (4) gives the heat generated due to friction over time, \( E_f \):

\[ E_f = \int_{t_o}^{t_f} Q_f dt = \int_{t_o}^{t_f} \rho_f C_p (T_{cw} - T_o) dt + \int_{t_o}^{t_f} \frac{d}{dt}(\rho V C_p T) \]  

The heat generated due to friction during the test, \( E_{ff} \), can be determined by measuring the inlet and outlet temperatures as well as the flow-rates of the cooling fluid. By ensuring that the sump temperature is maintained at a desired value, the heat loss due to friction as determined using equation (5) can serve as a valuable additional performance parameter [3].

MODIFICATIONS TO THE STANDARD EQUIPMENT

Installing a heat exchanger inside the test gearbox to facilitate sufficient heat exchange without compromising the ease of operation i.e. testing, gear removal, mounting and cleaning after the test, is problematic. Figure 1 shows the gearbox with an internal cooling manifold behind the gears and at the front a copper tube that exits the gearbox through the centering bush which is connected to an external heat exchanger.

![Figure 1: The modified test gearbox of the FZG-machine](image)

RESULTS

In this modified, constant temperature FZG-test, heat removed to maintain a constant operating temperature is determined by measuring coolant flow rate as well as inlet and outlet temperatures. This provides a valuable performance parameter for different lubricants, making it possible to distinguish between lubricants that differ only marginally in their general performance. Cooler temperatures can lead to thicker films and thereby better wear protection while anti-wear additives may become active at higher temperatures and offer improved wear protection [4]. Depending on the composition of the lubricant, it is thus possible for a lubricant to have improved or decreased wear protection at higher temperature. To ensure more representative and reliable results that are as relevant as possible to practice, the conditions under which the lubricant is evaluated in the laboratory should be as close as possible to those experienced in practice.

A summary of results obtained for the same product tested under the two sets of conditions, i.e. uncontrolled and controlled (fixed temperature), are shown in Table 1 below.

<table>
<thead>
<tr>
<th>Table 1 Summary of comparative tests on four lubricants</th>
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<tbody>
<tr>
<td>Lubricant</td>
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<td>Mass loss (mg) after 12 load stages (uncontrolled)</td>
</tr>
<tr>
<td>Mass loss (mg) after 12 load stages (controlled)</td>
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<tr>
<td>Motor amperage (A) during controlled test</td>
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<tr>
<td>Final temperature (°C) (uncontrolled)</td>
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<tr>
<td>Heat removed to maintain a constant temperature (kJ)</td>
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With the new test method, the influence of temperature on lubricant performance parameters like wear protection can be investigated. In principle, the test can be performed at any selected temperature, or over a range of temperatures. In addition, the amount of lubricant supplied to a system can be carefully controlled, enabling determination of optimum relubricating intervals. The problem of curing of certain types of lubricant can also be accommodated using the new test procedure.

One of the key factors in determining effectiveness of lubrication on large open gears is the quantification of wear. On the FZG test rig one of the advantages is that the gears are small and that they can be removed between load stages of the test for weighing. The same cannot be done for industrial open gear sets. Gravimetric quantification of wear is therefore not possible. Surface profilometry and computer surface imaging can assist in surface change detection.

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REFERENCES


