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Life Cycle Assessment of Rapeseed and Mineral Oil Based Fluid Power Systems

Thesis for the degree of Doctor of Philosophy, University of Bath, Bath, UK

Marcelle McManus

SLR Consulting limited, Treenwood House, Rowden Lane, Bradford-on-Avon, Wiltshire, BA15 2AU, UK
(marcelle_mcmanus@bigfoot.com; www.slrconsulting.co.uk)

In recent years, especially in the developed world, there has been a heightened awareness of environmental issues particularly in respect of the need to achieve sustainable development. This has had an impact on the design domain as it becomes recognised that the development of products and processes with a low environmental impact over their whole life-cycle is preferable to cleaning up during and after operation. In the case of fluid power systems, the focus of the thesis, the market is currently dominated by applications based on mineral oils as the working fluid.

Many companies and organisations are trying to become more environmentally friendly. Mobile hydraulic systems can often work in 'sensitive areas', such as forests and around lakes and rivers. Fluid power systems, although theoretically closed systems, often leak. Most of the time these leaks are slow and occur over many years. On some occasions the spills are larger, resulting in several litres of oil being spilled. For this reason many companies have decided to use biodegradable oil in their systems.

The main objectives of the research were therefore: to examine the life cycle of fluid power systems using alternative media: biodegradable oil and mineral oil; to examine the comparative impact of these systems over their life cycles using two case studies: forestry machines and road sweepers; and to determine whether LCA is a useful and suitable tool for use within fluid power engineering.

Hydraulic installations are generally optimised for use with mineral oil. Unfortunately, biodegradable fluids are not often compatible with all the components of a hydraulic system and so devices running on the biodegradable fluids often need to be specially modified. They also often require more specialised components and require more frequent oil changes. This means that over the whole life the use of biodegradable oil is not necessarily less of an environmental burden than the use of mineral oil.

An LCA is subject to uncertainty and error. Therefore, a large part of the study was devoted to the use of sensitivity analysis within life cycle assessment and life cycle impact assessment. The study analysed the sensitivity of the final results to the inventory data and also to the impact assessment used and the data used within the characterisation stages.

The study provides an original contribution to the knowledge of LCA of mineral oil and rapeseed oil based systems and the use of LCA in engineering design. It also provides an original contribution to the knowledge of sensitivity analysis within LCA.

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Error Calculation in Life Cycle Assessments

The aim of this work is to develop a method for calculating errors in Life Cycle Assessments (LCAs) that can be applied in practice. This method is developed by putting up a model that covers the different calculation steps of a Life Cycle Assessment as they are commonly used today. The model allows the calculation of true values for errors at different stages within the LCA calculation, and also in the final result of the LCA.

In the model, six different methods for calculating errors where implemented and analysed. Essential for the analysis was the goodness of fit of each method. The goodness of fit is the measure to what extent the error, as calculated by an approximation method, corresponds to the true value of the error ('true error'). Thus, the true error was used to validate the calculated error.

The error calculation method developed in this work distinguishes between the calculation of systematic errors and that of random errors. At first, systematic errors, being errors that are reproducible, are cleared from the input data of the LCA, and if necessary or desired, the systematic errors in the result of the LCA can be calculated. Both clearing and calculation can be done in an exact way, without the need of referring to approximation formulas.

In a second step, the random errors are calculated. The relative error turned out to be the essential parameter for discovering the goodness of fit of each method. Depending on the value of the relative error and the calculation step in the LCA, the method recommends *not* using certain approximation formulas. The Gaussian error propagation formula turned out to largely underestimate the error, if the relative error had higher values. A formula developed by Bader and Baccini performed better in these cases. With even higher relative errors only the Monte Carlo simulation, from the methods analysed, was able to calculate the errors correctly.

A systematic change of the parameter values accessible in each calculation step revealed distinct limits for the relative error specific for each calculation step in the LCA, and for each approximation formula. These limits span intervals specific for each approximation formula and each calculation step. In the calculation of an LCA, the relative error can be obtained either from input data or from a preceding calculation step. A check whether the error lies in the appropriate interval indicates whether an approximation formula should be used for calculating the errors in that calculation step.

The thesis is written in German; a full text is available at http://edocs.tu-berlin.de/diss/2001/ciroth_andreas.htm. An English article on the thesis is in preparation.

Dr.-Ing. Andreas Ciroth
GreenDeltaTC Tools & Consulting
Raumerstr. 7, D-10437 Berlin, Germany
ciroth@greendeltatc.com