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Life Cycle Assessment of Metal Removal Fluid systems in metalworking applications – Evaluation of environmental impacts using the example of crankshaft manufacturing

Motivation

The use of Metal Removal Fluids (MRF) or "coolants" in industrial metalworking applications is very common, due to the fact that their cooling, lubricating and flushing effects enable an efficient and economic machining process. Their usage reduces tool wear, improves surface quality and minimizes thermally induced defects. Normally, conventional water-miscible (emulsion or solution) or non-water-miscible (machining oil) MRF on mineral oil basis are used. The extraction, production, usage and disposal of mineral oil, however, have various negative ecological impacts. Also from a process chain perspective, the selection of the particular cooling lubricant has an ecological impact itself. A large part of the used cooling lubricant is dragged off during the process due to adhesion on the workpiece. Depending on the type of cooling lubricant used in the subsequent process step, a time-consuming intermediate washing has to be carried out. In order to prevent this inconvenience, Oemeta Chemische Werke GmbH developed the multipurpose oil "HYCUT", which can either be used as a non-water-miscible machining oil or as a water-miscible emulsion. Contrary to conventional cooling lubricants, it has been developed on the basis of renewable raw materials. It can be assumed that the usage of this native-based multipurpose oil will result in environmental advantages compared to mineral oil-based cooling lubricants. Thus, in cooperation with the Institute for Machine Tools and Production Technology of the Technical University of Brunswick, Germany, the potential environmental impacts of the multipurpose oil "HYCUT" have been examined by means of a Life Cycle Assessment (based on ISO 14040, without external critical review) and compared with those of a conventional mineral oil-based reference lubricant system.

Method – Life Cycle Assessment

In the sense of a holistic evaluation of the environmental impacts of products, the complete life cycle of a product is considered – from the extraction of raw material to production and usage to final disposal, in short, from "cradle-to-grave". Throughout this life cycle and in all processes examined, such as production and disposal, energy generation and transport, the resources consumed as well as the emissions produced are recorded and converted into environmental impacts. The results are expressed in relation to a lead substance. For example, the Global Warming Potential (GWP) is related to the lead substance CO_2 and specified in kg CO_2 equivalents. Further environmental impact potentials considered are acidification (in kg SO_2-eq), nutrient enrichment in soils and water (eutrophication in kg PO_4-eq) and the so-called abiotic depletion (in kg antimony (Sb)-eq), which is the consumption of mineral and fossil raw materials such as metals, crude oil, natural gas and coal. The Life Cycle Assessment has established itself for evaluating the complete life cycle of products and services. This method is internationally acknowledged and standardised. In this case study, the software "Umberto" with the database "ecoinvent" was used for carrying out the Life Cycle Assessment.

Framework of the case study

The Life Cycle Assessment (based on ISO 14040, without external critical review) was carried out within the framework of a case study at the engine plant of a German automobile manufacturer located in Austria. Here, the process chain of the crankshaft manufacturing was examined, which consists of the most varied machining processes such as milling, turning, deep drilling and grinding. The process chain is characterized by a frequent change in water-miscible and non-water-miscible cooling lubricants according to the specific requirements of the single machining processes (see illustration 1).

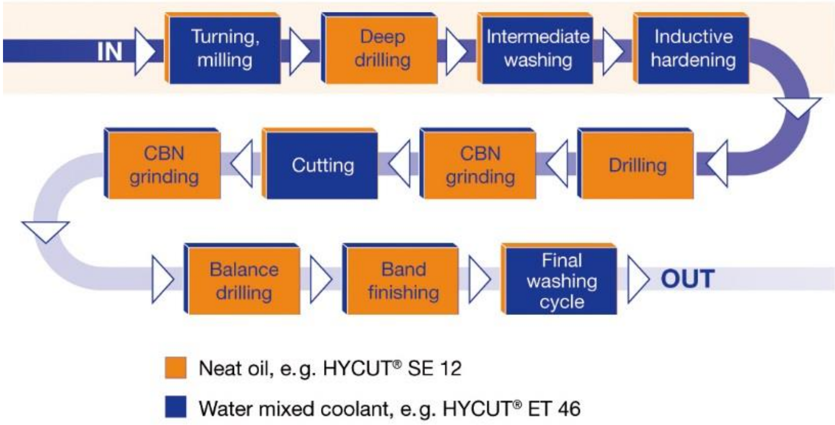

Illustration 1: Process chain layout

In practice, the process chain is already operated with the ester-based multipurpose oil "HYCUT", which is formulated, so that water-miscible and non-water-miscible components are compatible. Thus, the mutual introduction of lubricants adhering to the workpieces must not be avoided, but on the contrary, is desired. Compared to mineral oil-based reference products, the use of this cooling lubricant in the entire production line is much more efficient, because intermediate washing operations and waste of the MRF can be mostly prevented. Especially the re-use of the washing agent from the workpiece cleaning as cooling lubricant for the machining processes has a positive effect on the Life Cycle Assessment. In order to take full advantage of the multipurpose oil, the planners tailored the production chain design to the particular lubricant. For example, several systems for the cleaning of workpieces, which are normally required to avoid the dragging out of MRF, were not installed. As well, the consumed cleaning agent from the remaining intermediate washer can be pumped through a piping system directly in a MRF system for recycling purposes.

Two different scenarios were illustrated in the case study. The "HYCUT" scenario representing a system consisting of compatible lubricants based on renewable raw materials and a reference scenario describing the usage of conventional mineral oil-based cooling lubricants. For both scenarios, the annual production of crankshafts (for 4 and 6 cylinder engines) within this process chain is defined as the functional unit. Hence, the consumption of cooling lubricants and the disposal quantities related to the annual production are the basis for the comparative Life Cycle Assessment.

Life cycle inventory and impact assessment

The case study compares the two described scenarios. Illustration 2 demonstrates that in all considered environmental impact categories and with regard to the entire life cycle the usage of the "HYCUT" system results in significantly lower environmental impacts (40-60%) than the reference system.

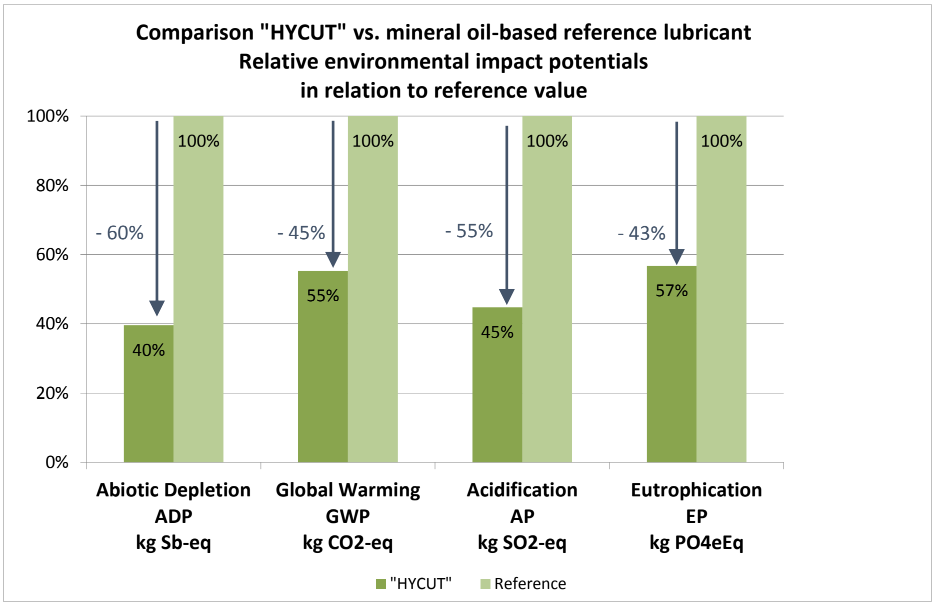

Illustration 2: Overview of the relative environmental impact potentials

Regarding the Global Warming Potential, the examined case generated savings of about 470 t CO_2-eq in the annual production. These savings, for example, correspond to the environmental impact caused by the annual driving operation of 158 passenger cars[1]. Further comparisons are shown in table 1.

Table 1: Comparisons related to savings in GWP

Key figure	Unit	Savings
Relative Savings	%	**45%**
Absolute Savings	t CO_2-eq	**474**
Comparison Cars	Number Cars	**158**[1]
Comparison People	Number People	**43**[2]
Comparison Flight	Number Circumnavigation	**51**[3]

[1] Driving distance of 20,000 km / year and 0.15 kg CO_2-eq / passenger-kilometre
[2] Consumption of 11 t CO_2-eq / year (average of a German)
[3] Flight distance of 40,000 km around the world and 0.23 kg CO_2-eq / passenger-kilometre

The determined absolute values are case-specific and depend on the basis of comparison, the examined system and the considered processes. The relative values indicate the general trend of the comparison. Thus, based on the Life Cycle Assessment it could be proved, that the use of the multipurpose oil “HYCUT” in metalworking applications leads to much lower environmental impacts than the use of a conventional mineral oil-based cooling lubricant with the same benefits.