LESSONS LEARNED REFLECTION ON DIOXINS IN THE LIFE CYCLE ASSESSMENT OF LUBRICATING OIL

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Introduction

Over the past ten or so years there have been continuing efforts in the industry responsible for manufacture of lubricating oils to reduce levels of residual chlorine in the products. This has been driven by a sense that reduced chlorine in the oils will lead to reduced emissions of the highly toxic polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/F).

The majority of the chlorine in the lubricants arises as a residual contaminant in dispersants which are manufactured by the "conventional" route and the levels of chlorine in the final product (for vehicles) has been reduced over time from 300-500ppm to typically 100-150ppm.

Reducing chlorine levels significantly further would require a shift to dispersants produced by an alternative process – direct alkylation (DA) which does not use chlorine so that levels in the oil are linked to carry over from other components (<20ppm). The DA process requires higher temperatures and the dispersant has different properties compared to the "conventional".

Lubrizol initiated a life cycle assessment project as a means to formally and systematically assess the environmental effects of the proposed restriction on chlorine in oil.

Materials and Methods

This study compared the life-cycle impacts for two scenarios – passenger car (PC) and heavy duty (HD). We compared a gasoline passenger car lubricant formulated with conventional dispersant against one formulated with a DA dispersant. The functional unit applied in the study for comparative purposes was 1000 litres (equivalent to 900 kg) of 10W-40 lubricant at the ACEA A3/B3/B4 level. Euro 3 emissions levels were used (typical of current vehicle fleet) with 5 litres of oil change per 20,000 km (c12,000 miles) and a fuel consumption rate of 8 litres per 100 km (c 35mpg).

For heavy duty (HD) we considered a diesel truck with 15W-40 lubricant designed to meet ACEA E5, 35 l of oil per change and drain interval of 50,000 km (c31,000 miles), meeting Euro 3 emissions standards and with fuel consumption of 36 l/100km (c8 mpg).

The LCA considered the following stages:

1. Raw material production
2. Dispersant production
3. Lubricant production
4. Lubricant distribution
5. Lubricant usage
6. Lubricant disposal

Packaging and transport of lubricant were identical and not considered. Since waste oil disposal varies so widely, a scenario approach was adopted and a sensitivity analysis was performed to determine the effect on overall impacts (these were based on country examples that ranged from waste oil mostly burned with no controls to waste oil use with high standards of pollution control and significant amounts of regeneration).

These parts of the system can be represented graphically, Figure **1**.

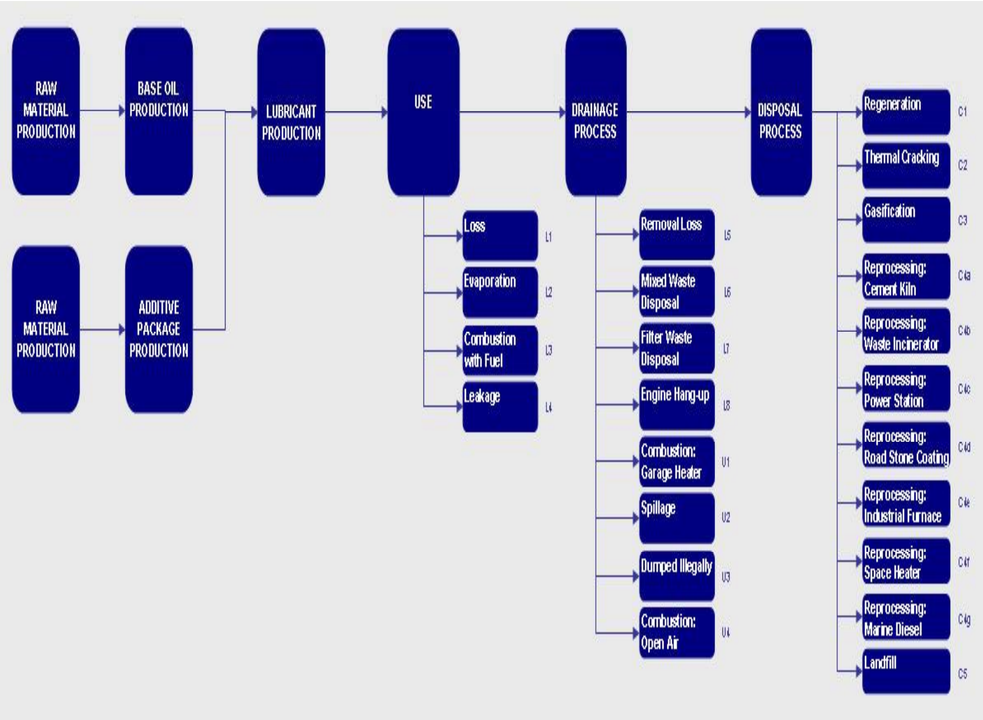

Figure 1 LCA system flow

The impact assessment quantifies the results in terms of several different impact categories. Each system was assessed according to the categories that address the main environmental issues associated with road transport:

1. Depletion of abiotic resources
2. Climate change
3. Acidification
4. Human toxicity – including that arising from PCDD/F

The methodology used to determine these impacts was the CML 2.7 approach developed at the University of Leiden. To test the robustness of the results, the data were also examined using methodologies from EPS (Chalmers University), EDIP/UMIP (Danish team) and Eco-Indicator 99 (Swiss team) LCA methodologies, all of which gave comparable results. The CML system bases toxicity impact on a multimedia model so includes indirect exposure which is most significant when addressing PCDD/F details can be found in papers by Huijbregts *et al*[1,2].

In order to ensure that the results were well founded detailed data was gathered from the manufacturing processes to give material and pollutant flows as well as energy consumption. To test robustness of the conclusions sensitivity analysis was performed on important variables.

Results and Discussion

The first assessment was made on the basis that the lubricants achieved equal performance and this showed that there were, at most, very small differences in life-cycle impacts between the two formulations. This is to be expected since the change in the manufacturing process of one component of the additive package has small effects compared to the manufacture, use and disposal of the bulk of the finished lubricant. However, isolating the dispersant manufacture element showed clearly that the impacts relating to use of DA dispersant were higher than conventional for two main reasons – the higher energy inherent in the manufacturing process and the higher treat rates required to achieve equal performance due to differences in the physical/chemical properties of the dispersants. These inherent differences mean that each dispersant has advantages and disadvantages in terms of performance.

Two important issues arose at this stage – relating to PCDD/F and to fuel efficiency. Although emissions of PCDD/F had been included in the life-cycle assessment and the overall impact results were insensitive to these (PCDD/F contributed only a very small amount of total life-cycle toxicity) there was a valid question that since these pollutants were of such concern any adverse impact on these could overrule other considerations. Our review of the literature had shown that there was no data to suggest that changes in the level of chlorine (at least within realistic bounds) in the oil would impact on emissions of PCDD/F, however, in the absence of detailed testing there remained uncertainty. Consequently, we carried out a testing programme.

The issue of fuel efficiency became a major focus of study. The dispersants used in lubricating oils can impact on the frictional properties of the oils – in general the higher the level of dispersant the more friction is increased and conventional dispersants tend to affect friction less than DA dispersants. Given that the DA dispersant needs to be added at greater rates than the conventional and is inherently more damaging to frictional properties the end result is that engines using DA oils can show higher fuel consumption in use. This important effect was also tested on engines and in the field to arrive at an estimate of the impact that should be included in the LCA.

In the light of the experimental work on dioxins (reported elsewhere at this meeting and last year[3]) and the findings on fuel efficiency the baseline LCA used a difference in vehicle fuel economy of 0.6% and no change in emissions of PCDD/F between the two formulations. The results showed a major difference between the life-cycle impacts of the two dispersants – see Table 1. The results for the heavy-duty assessment gave different absolute numbers but the same overall message – see Table 2

Impact	Units	Conv/PC, 10W40, A3/B3	DA/PC, 10W40, A3/B3
Abiotic depletion	kg Sb eq	11.2	57.9
Global warming	kg CO_2 eq	1550	7800
Human toxicity	kg 1,4 DB	-9.89	1280
Acidification	kg SO_2 eq	-1.71	16.6

Table 1 LCA impact results passenger car – accounting for fuel efficiency impact

Impact	Units	Conv/HD, 15W40, E5	DA/HD, 15W40, E5
Abiotic depletion	kg Sb eq	6.57	66.2
Global warming	kg CO_2 eq	913	10400
Human toxicity	kg 1,4 DB	-130	949
Acidification	kg SO_2 eq	-6.6	8.58

Table 2 LCA impact results heavy duty – accounting for fuel efficiency impact

Results are expressed on the basis of mass equivalent of reference compounds for consistency. Negative values indicate that for a particular category the overall impacts are beneficial, this may appear counter intuitive but arises where other impacts are displaced – in this case where used oil is used productively in, for example, power plants and can displace a more polluting conventional fuel such as coal.

The principal reason that the difference between the two formulations is so marked is that because of the impact on fuel efficiency the DA case is effectively the life-cycle impacts of producing and disposing of 1000 l of lubricant *plus* the production and pollution impacts of the *additional* c2000-3000 l of fuel that would be consumed to cover the same distance.

The analysis of sensitivity against changes in the pattern of disposal and the magnitude of the fuel efficiency difference showed that the same overall result was seen – for these impact categories the life-cycle impacts of the DA option were larger than the conventional, the magnitude changes with the different scenarios but the conclusion is the same.

Conclusions

The main conclusion from this work is that in order to make informed decisions relating to formulation of lubricating oils a full assessment of the life-cycle impacts should be undertaken. Isolated focus on only one aspect of the process or material can lead to overlooking the bigger picture.

Whilst the high toxicity and high profile of PCDD/F means they are the focus of much concern, it is important to consider wider environmental impacts, especially in situations such as with motor vehicles which are not a major source of PCDD/F emissions.

The life-cycle assessment framework allows the inevitable trade offs to be assessed – in this case a restriction in chemical composition of lubricant against the unintended consequence of increased energy consumption in production and detriment to fuel economy in the vehicle.

Establishing the proper boundaries of the study is crucial and generating valid data important – in particular being able to develop scientifically sound test data to test important relationships – in this case fuel efficiency impact and effect on PCDD/F emissions.

Such an approach can help to identify key aspects of a process where significant impacts occur as well as where changes could be made that would alter overall impacts on the environment – in this case the work showed that focusing on fuel efficiency would yield the greatest benefits.

Clearly, changes to formulations designed to enhance fuel efficiency should be assessed to ensure that other impacts are not unforeseen or unacceptable.

Acknowledgements

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