Recycling of industrial lubricant oil
A SCREENING LCA OF ROCCO OIL CLEANING SYSTEM
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Abstract

Lubricant oils are used for a range of applications. One of the applications are as rolling oil for drawing of metal wires. Sandvik AB is a company that produces metal wires and other products using rolling mills and are therefore dependent on lubricant oils for their operation. A problem Sandvik AB encountered were that contaminants in the oil that comes from the operation itself damaged the wires in various ways and leads to stops in the production and material waste. Conventional filter cleaning was not effective enough which lead to an increased concentration of small particles and a need to change the oil in the system four times per year. RecondOil AB come up with a way to recycle the oil and remove particles from the oil, that is too small or light to be removed with filters or centrifuges, with a system called ROCCO.

The goal with this screening LCA is to quantify the environmental impacts of the two systems, regarding global warming potential, acidifying potential and human toxicity potential. The geographical boundary is Sweden. The functional unit is based on production of wires, but as the production numbers is not available for the public a ten-year production of wires will be set to 100 units for the ROCCO system and will be the functional unit.

Global warming potential, acidifying potential and human toxicity potential are reduced with around 90 percent after the installation of ROCCO, this is roughly equal to the reduction in oil use compared to the original system. After weighting of the impact categories, with the EDIP97 method, it is possible to conclude that the global warming potential is the impact category with the largest environmental impact of the impact categories assessed in this study.

If the waste oil is re-refined instead of incinerated, as it has been calculated in the main model, the impact on global warming is about 15 percent lower with the ROCCO system compared with the original system. If the ROCCO system was run with a German energy mix instead of Swedish energy mix, as in the main model, the impact on global warming is about 60 percent lower with the ROCCO system compared with the original system. If the ROCCO system is run on German energy mix and the waste oil are re-refined the impact on global warming are larger with the ROCCO system compared with the original system.
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1 INTRODUCTION

Lubricant oils are used for a range of applications. One of the applications are as rolling oil for drawing of metal wires. Sandvik AB is a company that produces metal wires and other products using rolling mills and are therefore dependent on lubricant oils for their operation. A problem Sandvik AB encountered were that despite conventional filter system were used, contaminants in the oil, that comes from the operation itself, damaged the wires in various ways and leads to stops in the production and material waste (RecondOil AB 2012a). To keep the production going, Sandvik AB changed the oil in the system four times per year (RecondOil AB 2012a). The oil was most likely then incinerated. The incineration of old oil and refining of new oil will result in emissions of GHG (Green House Gases) and a number of other emissions. RecondOil AB has come up with a way to keep the oil constantly clean, and at the same time recycle 90-98 percent of the oil¹. The constantly clean oil resulted in less productions stops and less material waste, which increased the production by 25 percent (Sandvik AB 2012). RecondOil AB uses a separation booster that collects particles that are too light or too small to be able to filter out or separate from the oil in a centrifuge. The booster is heavier than the oil and can therefore, together with the collected particles, be removed with the help of a centrifuge. (RecondOil 2012b)

RecondOil AB have calculated the economic benefits of installing the system and now they want to know how big the environmental benefit is to install this cleaning system that they have given the name ROCCO. This system is installed on site at Sandvik AB and are connected to the lubricant system of the rolling mill.

1.1 METHOD

To investigate the environmental impact from the use of lubricant oils, with or without oil recycling using the ROCCO system, a screening life cycle assessment (LCA) will be performed. LCA is a good method to use when comparing the environmental impact between products, services or processes and when quantitative data is at hand rather than qualitative. The method is flexible which makes it applicable in many situations. LCA is standardised according to ISO 14040 which makes it one of the most established methods. (Rydh et al. 2002, 37-48) By calculating the material and energy flow during the lifetime it is possible to estimate the environmental impact of a product, service or process. The impact categories that will be included are GWP, AP and HTP.

1.2 IMPACT CATEGORIES

Global Warming Potential (GWP)

Gases like carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) contributes to the global warming by absorbing some of the heat radiation (long wavelength) that would otherwise leave the atmosphere, at the same time as the sunlight (short wavelength) can pass through unobstructed, this increases the temperature in the atmosphere (Bernes 2007, 22). To get a fair view of the impact of the different greenhouse gases they are locked upon as

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¹ Sundström, Fred. Managing Director at recondOil AB. 2016. E-mail 19 May.
they all are carbon dioxide and are therefore written as carbon dioxide equivalents (CO$_2$eq). Methane as an example are 25 times as potent as a greenhouse gas as carbon dioxide. That means that 1 kilo of methane has the same impact on the global warming as 25 kg of carbon dioxide and can therefore be expressed as 25 kg carbon dioxide equivalents. (Brander 2012, 2-3)

**Acidifying potential (AP)**

In a geological time frame there are a natural acidifying process in soils, freshwater, and oceans (Lükewille, Alewell 2008, 23). However, emissions of gases like sulphur dioxide (SO$_2$), and nitrous oxides (NO$_x$) contributes to an accelerated acidification by enhancing natural processes (Lükewille, Alewell 2008, 23) when nitrous oxides and sulphur dioxide are converted to nitric acid (HNO$_3$) and sulfuric acid (H$_2$SO$_4$) through oxidation and dissolution (see fig. 1-3). One effect of acidifying emissions is the decline in aquatic life due to acidic water bodies. The aquatic life does not necessarily decline due to the acidification itself. Another effect of acidification is an increased leaching of heavy metals from terrestrial soils and bedrocks, as the acidification makes the metals in the terrestrial soils and bedrocks soluble to infiltrating water. (Pidwirny 2006)

**Human Toxicity Potential (HTP)**

Exposure to air pollutions such as sulphur dioxide or to heavy metals can cause a variety of health effects on humans, such as damage to the respiratory or the nervous system (Kampa, Castanas 2008). The emissions will be expressed in 1,4-dichlorobenzene equivalents (1,4-DCEq).

### 1.3 Weighting Method

The impact categories will be weighed against each other using the EDIP97 (Environmental Design of Industrial Products) weighting method. EDIP97 assesses environmental impact, resource use and effects in the working environment, and are doing so on global, regional and local levels (Rydh et al. 2002, 126). The weighting of the potential environmental impact for this method is based on politically set environmental goals. Resource use is weighted based on the ratio of the annual global recovery and global recoverable reserves of the resource. The impact on the working environment from the different data categories are weighted based on reports on safety at work and work related injuries. (Rydh et al. 2002, 126)

### 1.4 Technical Description

The function for both the original lubrication system and the lubrication system after the installation of ROCCO is to enable continuous production of metal wires. In fig.1-3 the original system is shown in the red dotted box in a simplified way. The lubricant oil runs from the oil tank through the drawing mill and then runs through a filter (not shown in the figure) on the way back to the oil tank. The ROCCO system contains of a centrifuge and a container were the separation booster is added. The oil runs, as for the original system, through the drawing mill and then runs back to the oil tank (without going through a filter). From the main lubricant system, a side flow is taken out that goes to a container were the separation booster is added that collects the impurities in the oil. The mix of oil and separation booster then goes through a centrifuge and due to the high density of the separation booster the
impurities can be removed from the oil as a sludge containing impurities, separation booster and a small amount of oil. The clean oil is then put back into the lubricant system.

Figure 1-3. Simple illustration of the lubrication system before (red box) and after (green box) the installation of the ROCCO system.

Fig.1-4 shows a process tree over activities included in the study of lubrication for wire drawing before the installation of ROCCO, i.e. the oil was changed frequently.

Oil are extracted and transported to a refinery. From the refinery we get the base for the lubricant oil, further to produce lubricant oil some additives are needed to give the oil the right properties to get increased lubricating properties etc. At Sandvik AB the lubricant oil is used as lubricant in the drawing progress of wires in their rolling mill. To remove the biggest particles that contaminates the oil it runs through some oil filters. The oil filters cannot remove all particles as some of them is too small to get caught in the filters, after some time the oil will be too contaminated to fully function as a lubricant and has to be replaced by new oil. This was usually done four times per year (RecondOil AB 2012b). The removed oil and filters will most likely be incinerated.

Fig.1-5 shows a process tree over activities included in the study of lubrication for wire drawing after the installation of ROCCO, i.e. the oil is cleaned continuously.

The process in fig.1-5 are the same as in fig.1-4 up until when the lubricant oil enters the lubricant system at Sandvik AB. With the ROCCO installed the particles in the oil are removed continuously which means that the oil does not have to be changed four times per year (RecondOil 2012b). Some oil will be lost in the cleaning process and has to be replaced (RecondOil 2012a). The separated particles have to be disposed of and incineration seems like the most likely measure. After 10 years there will probably be some sort of maintenance on the lubricant system and the ROCCO and all oil will maybe be replaced and the removed oil will most likely be incinerated.

1.5 PURPOSE

Fossil carbon based products, as lubricant oils, is a finite resource that can have several environmental impacts during its life time. The purpose of this study is to assess the environmental benefits, if there are any, of cleaning and reuse lubricant oil instead of dispose it in some way, e.g. to incinerate it.
Figure 1-4. Process tree of the system before the installation of ROCCO (Original system).

Figure 1-5. Process tree of the system after the installation of ROCCO.
The goal of this study is to investigate the environmental impact from the use of lubricant oils, that is essential in the wire drawing process, with or without oil recycling using the ROCCO system. In the study impact from GWP (Global Warming Potential), AP (Acidifying Potential) and HTP (Human Toxicity Potential) will be assessed.

The assessment will cover cradle to grave, and that is cradle to grave for the oil. The assessment will start with the extraction of the oil and end with the disposal of it.

In the main model the crude oil and natural gas are extracted, the crude oil is refined and the refined oil product together with some additives are used to produce lubricant oil. To run the ROCCO system some electricity are needed and in the main model the electricity is assumed to be based on Swedish energy mix. The waste oil from the two systems is assumed to be incinerated, as well as the centrifuge sludge from the ROCCO system and the oil filters from the original system.

The impact categories will be weighed against each other. Weighting is used when several types of impact categories has to be weighed against each other. The result obtained after the weighting is the actual impact from the impact categories and is done to give a fair comparison between the impact categories, as some impact categories can have a larger environmental impact even though the emissions are lesser. To do this, weighting indexes that describes the impact of emissions and resource use related to each other are used to estimate which data category that contributes to the largest environmental impact. (Rydh et al. 2002, 83) There is several weighting methods that ranks data categories differently. EDIP97 are used as weighting method in this LCA and is further explained in section 1.3.

The study includes three alternative scenarios were in the first scenario the waste oil is re-refined instead of incinerated. In the second scenario the Swedish energy mix are replaced with a German energy mix. The third scenario is a combination of the two aforementioned scenarios. These scenarios represent the sensitivity analysis that will be presented in section 5.1 in this paper.

2.1 TECHNICAL SYSTEM
The technical system for lubrication oil use without or with the oil recycling system installed is described in section 1.4 and the figures 1-3, -4 and -5, respectively.

2.2 STUDIED FUNCTIONS
The function studied in this paper are to provide lubrication in the process of drawing metal wires. The study assesses the environmental load during ten years from providing lubrication with and without oil recycling using the ROCCO system. To be able to compare the two lubrication system the environmental load will be linked to the production of metal wires, as the lubrication systems ultimate function is to enable continuous production. The most suitable should be to express the production of metal wires in tonnes as the thickness of the wires varies depending on the type of wire that are produced at the moment, and therefore it could be misleading to express the production in meters. However, this is something Sandvik AB do not want to reveal. As the production data of the metal wires is not accessible the production after the installation will be
estimated. The exact number that is used is not important as the parameter that is important to include is the increase in production. It will therefore be assumed that the production is one hundred units in a ten-year period after the installation of ROCCO (80 units before) and the functional unit will be based on this.

2.3 FUNCTIONAL UNIT
The functional unit are one hundred produced units of metal wire.

2.4 SYSTEM BOUNDARIES
The boundaries of the technical system included the activities:

- Raw material extraction
- Refining
- Production of lubricant oil, additives and separation booster
- Recycling of the lubricant oil
- Disposal of waste oil, oil filters and centrifuge sludge
- Transports

For the geographical boundary, the process is modelled to be set in Sweden, despite this the extraction of the oil are included as it is most likely a significant contributor to the environmental impact from the oil. The time frame are ten years.

3 LCI

In the LCI (Life Cycle Inventory) the relevant material or energy flows in and out of a process system are quantified by gathering data and perform calculations, these flows are called data categories (Rydh et al. 2002, 63). As the production went up with 25 percent after the installation of ROCCO the functional unit was set to 100 produced units of metal wires which is the amount of wires that are produced after the installation of ROCCO during a ten-year period. The amount of units that was produces with the original system was 80. If the original system shall meet the requirements of the functional unit, that is 100 produced units of wire, the inventory data for the original system has to be multiplied by 1,25. This is done to give a fair comparison between the systems (Rydh et al. 2002, 50-53). In the following sections, 3.1 and 3.2, the material flows are presented in material flow per functional unit.

3.1 THE ORIGINAL SYSTEM — THE SYSTEM WITH FREQUENT OIL CHANGES
The numbers in the headlines in the following section refers to the steps presented in figure 1-4.

1. Extraction of oil and natural gas
The emission data for extraction of oil are based on a combined extraction of oil and natural gas this is done because natural gas, are needed in the process of producing the additive. From every tonne extracted raw material, 78,6 % are crude oil and 21,3 % are gas (process 1 in appendix II).

2. Refinery
In the refinery the crude oil is separated into different oil products, for example vehicle fuels, heating fuels and lubricants. In the refining process, the crude oil is heated and the different oil products are separated due to the different boiling point of the products. How much of the different products that
are possible to extract are dependent on the composition of the crude oil. (SPBI, 2016) Some 135 (allocated) tonnes of crude oil are needed to produce the 144 m³ of refined oil product, that in this study is base oil, needed in the production of lubricant oil and additive to the lubricant oil (calculations in appendix I). The calculated emissions are based on emission data from refining of crude oil by distillation (process 2 in appendix II).

3. Production of lubricant oil
Some 150 m³ of lubricant oil are needed to feed the system. The calculation in this LCA are based on that the lubricant oil consists of 87,6% base oil and 12,4% additives (process 3 in appendix II).

4. Additive
The additives are needed to give oils some specific properties depending of the application of the oil. The main function of a lubricant oil is to lubricate which is enhanced by friction modifiers, antiwear and extreme pressure additives, but an industrial lubricant oil also contains additives such as antioxidants, viscosity modifiers, corrosion inhibitors etc. (Ahmed & Nassar 2011) In this study it will be assumed that all additives are an alcohol ethoxylate, which is a surfactant and is used as an additive in oil among many applications (HERA 2009), as a rough approximation. To produce the 18,6 m³ of alcohol ethoxylate needed to produce the 150 m³ of lubricant oil, some 12,8 m³of basic oil and 6 m³ of natural gas are needed (calculations in appendix I) (process 4 in appendix II). The emission data for the production of the additives is based on a combined extraction of oil and natural gas and refining of crude oil (process 1 and 2 in appendix II).

5. Sandvik AB rolling mill
The lubricant system for the rolling mills at Sandvik AB contains 3m³ of lubricant oil. The system has a flow of 18 m³ per hour. During the process metal particles and other impurities are accumulated in the oil, which can damage the metal wires during the production. (RecondOil AB, 2012a) To keep the material waste down and the production running the oil has to be changed four times per year (Sandvik AB, 2012). This will result in a 12 m³ per year that will enter and leave the lubricant system, over a ten-year period that number will be 120 m³ and per functional unit that number is 150 m³ (calculations in appendix I).

6. Oil filters
Before the ROCCO were installed the cleaning of the oil was done by filters. It is assumed that two filters were installed and that they were changed at the same time as the oil, i.e. four times per year resulting in 80 filters over a ten-year period which will be 100 oil filters per functional unit.

7. Incineration of oil and oil filters
When the oil and the filters have been changed it has to be discarded. The assessment will be based on that 150 m³ of oil and 100 oil filters are incinerated. The emissions from incineration of oil and oil filters is based on data from combustion of waste oil and combustion of oil filters (process 5 and 6 in appendix II).

Transports
The transports are not shown in the figure but are included in the LCA. The transports that is included are transport of oil from the refinery, Preemraff in Lysekil, to Sandvik AB and the transport of waste oil from Sandvik AB to Ragn sell’s oil incineration facility in Halmstad. The emissions are based on data on emissions per ton-kilometre for trucks (Izzo & Myhr 2015). The total transports for the original system is 165 780 ton-kilometres per functional unit (calculations in appendix I)
3.2 The ROCCO System

The numbers in the headlines in the following subparagraph refers to the steps presented in figure 1-5.

The stages 1-4 are the same as the system before the installation of ROCCO but there is some quantitative difference in the material flow.

1. Extraction of Crude Oil and Natural Gas

This stage is the same as before ROCCO.

2. Refinery

The refining of the oil is the same in this process but only about 13,4 (allocated) tonnes of crude oil is needed to produce the 14,3 m³ of basic oil and additives for the production of lubricant oil and the separation booster (calculations in appendix I). The calculated emissions are based on emission data from refining of crude oil by distillation (process 2 in appendix II).

3. Production of Lubricant Oil

8 850 litre of lubricant oil are needed to feed the system (calculations in appendix I). The calculation in this LCA are based on that the lubricant oil consists of 87,6% base oil and 12,4% additives (process 3 in appendix II).

4. Additive

To produce the 1 096 litre of alcohol ethoxylate needed to produce the 8 850 litre of lubricant oil, some 756 litre of base oil and 357 litre of natural gas are needed (calculations in appendix I) (process 4 in appendix II). The emission data for the production of the additives is based on based on a combined extraction of oil and natural gas and refining of crude oil (process 1 and 2 in appendix II).

5-7. Sandvik AB Rolling Mill and ROCCO

The lubricant system contains of 3m³ of oil as before the installation of ROCCO. The difference is that the oil does not have to be changed 4 times per year as the oil are cleaned continuously. The flow is as before 18 m³ per hour, from this flow 0,8 m³ per hour are transported to a tank were the separator booster are added that collects the impurities in the oil. After he booster is added the oil passes through a centrifuge were the separation booster together with the impurities is removed from the oil. (RecondOil AB, 2012a) With this system 90-98 percent of the oil can be recycled compared to if the oil would be changed four times per year. The calculation in this LCA will be based on that 95 percent of the oil are recycled, the remaining 5 percent follows the impurities out of the system. This means that approximate 8,850 litre of oil are added during a ten-year period, including the first filling (calculations in appendix I). 333 MWh are needed to clean the oil under a ten-year period with ROCCO that has an estimated effect of 8 kW² (calculations in appendix I). The emissions from the electricity used for running ROCCO are based on Swedish energy mix (Vattenfall AB 2012).

8. Separation Booster

The separation booster is added to collect all the impurities in the oil so that they can be separated with the help of a centrifuge. Exactly which chemical and what type of chemical that are used are a company secret. To be able to estimate the environmental impact from the separation booster, emission data from the production of alcohol ethoxylates was used as a rough approximation², which the emission data is based on (process 4 in appendix II). Some 8 320 litre of booster are needed during a ten-year period (calculations in appendix I).

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² Persson, Thomas; Process specialist at recondOil AB. 2016. Interview 10 May.
³ Östberg, Thomas; R&D Manager at recondOil AB. 2016. E-mail 20 Apr.
9. Disposal of separated impurities

The sludge that are removed from the system and are most likely then incinerated. The sludge consists of oil, separation booster and impurities. In a ten-year period 6000 litre of oil and 8320 litre of separation booster will be removed from the system as sludge and transported to an incineration facility. The emissions from the incineration of the sludge is calculated from the emission data from combustion of waste oil (process 5 in appendix II). The impurities that consists of metal particles etc. will be overlooked as the quantity of the metal particles in the sludge should be roughly the same as in the removed oil in the original lubricant system and therefore there will not be a different in the emissions of these metals between the systems. And as the purpose of this LCA is to quantify the differences in environmental impact this will not be relevant to look upon.

10. Incineration of oil

This assessment is based on that all the oil are removed after ten years. This means that 2850 litre (3m³ minus losses during the process) of oil are incinerated. The emissions from incineration of oil is based on data from combustion of waste oil (process 5 in appendix II). It is however not clear if all the oil needs to be removed after ten years or if it is possible to continue to run the system and only add the quantity of oil that are lost in the process.

Transports

The transports are not shown in the figure but are included in the LCA. The transports that is included are transport of oil and separation booster (even though the booster are probably produced elsewhere but the raw material are from here) from the refinery, Preemraff in Lysekil, to Sandvik AB and the transport of waste oil and centrifuge sludge from Sandvik AB to Ragn sell’s oil incineration facility in Halmstad. The emissions are based on data on emissions per ton-kilometre for trucks (Izzo & Myhr 2015). The total transports for the ROCCO system is 20 000 ton-kilometres (calculations in appendix I)

3.3 Compilation of inventory

The figures in table 3-1 are the total emissions from all the processes calculated from the flows and reference data presented in section 3.1 and 3.2. Each material flow for each process are multiplied with the emissions that are released during the reference process. As an example, the amount of crude oil that needs to be extracted to supply the ROCCO system with lubricant oil and separation booster is about 13,4 tonnes. The CO₂ emissions from crude oil extraction is about 78 kilograms per tonne of crude oil, resulting in about 1045 kilograms of CO₂ emissions from this process.
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<th>Emission to</th>
<th>1. Extraction of crude oil and natural gas (kg/FU)</th>
<th>2. Production of lubricant oil (kg/FU)</th>
<th>3. Production of separation booster (kg/FU)</th>
<th>4. Cleaning the oil (kg/FU)</th>
<th>5. Combustion of sludge (kg/FU)</th>
<th>6. Oil filter combustion (kg/FU)</th>
<th>7. Oil combustion (kg/FU)</th>
<th>8. Transports (kg/FU)</th>
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Table 3-1. Total emissions per functional unit from the original system and the ROCCO system.
4 LCIA

In the LCI A (Life Cycle Impact Assessment) the figures from the inventory will be used to assess the environmental impact of the system. If the numbers from the inventory are presented as they are it could be difficult to assess which inventory data that is important from an environmental point of view. To make it easier to comprehend there is some methods to apply. The first method is to sort the data categories in to environmental impact categories, this is called classification. Which impact category the different data categories is put in depends on scientific causations and some data categories can be put under several impact categories. The next method is characterization where the inventory data is multiplied with a characterization factor. By doing this it is possible to relate different emissions to each other by expressing them as an equivalent of a certain substance. As an example, it is common to express emissions that contributes to global warming as carbon dioxide equivalents (CO$_2$eq). (Rydh et al. 2002, 79-80)

4.1 TOTAL EMISSIONS

The total emissions from the system before and after the installation of ROCCO can be seen in tab.4-1 and 4-2. They describe which substances that are emitted, where the emissions are emitted, the quantity and which impact category it belongs to. To be able to compare the different emissions within each impact category they are multiplied with the characterization factor for the specific emission. They are then expressed in carbon dioxide equivalents (CO$_2$eq) for Global Warming Potential (Brander 2012, 2-3) sulphur dioxide equivalent (SO$_2$eq) for Acidification Potential (Guinée 2002, 344) and 1,4-dichlorobenzen equivalents (1,4-DCBeq) for Human Toxicity Potential (Guinée 2002, 190-197). Some of the emissions contributes to more than one impact category, for example sulphur dioxide that contributes to both Acidification Potential and Human Toxicity Potential. By the tables 4-1 and 4-2 it is possible to see that the emissions of carbon dioxide equivalents, sulphur dioxide equivalent, and 1,4-dichlorobenzen equivalents have been reduced by about 90 percent after the installation of ROCCO. The reduction of carbon dioxide equivalents and sulphur dioxide equivalents are mainly due to the decreases in the amount of waste oil that goes to incineration (see fig.4-1 and 4-2). The reduction of 1,4-dichlorobenzen equivalents are mainly due to the decreased production of lubricant oil and that no filter incineration is needed (see fig.4-3). The reduction in emissions is roughly equal to the reduction of oil use.
### ROCCO

<table>
<thead>
<tr>
<th>1. Data category for emissions</th>
<th>2. Emission to Inventory data (kg/FU)</th>
<th>3. Classification of environmental impact category</th>
<th>4. Characterization factor (CO₂eq/kg emission) (Brander 2012, 2-3)</th>
<th>5. Characterization factor (SO₂eq/kg emission) (Guinée 2002, 344)</th>
<th>6. Characterization factor (1,4-DCBeq/kg emission) (Guinée 2002, 190-197)</th>
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<th>8. Total emission kg CO₂eq (2. x 4.)</th>
<th>9. Total emission kg SO₂eq (2. x 5.)</th>
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Table 4-1. The total emissions from the system after the installation of ROCCO.

### ORIGINAL

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<tr>
<th>1. Data category for emissions</th>
<th>2. Emission to Inventory data (kg/FU)</th>
<th>3. Classification of environmental impact category</th>
<th>4. Characterization factor (CO₂eq/kg emission) (Brander 2012, 2-3)</th>
<th>5. Characterization factor (SO₂eq/kg emission) (Guinée 2002, 344)</th>
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<th>9. Total emission kg SO₂eq (2. x 5.)</th>
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<td><strong>653</strong></td>
<td><strong>29,54</strong></td>
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Table 4-2. The total emissions from the system before the installation of ROCCO.
4.2 **GLOBAL WARMING POTENTIAL**

The processes that in these cases contributes most to the global warming is combustion of the sludge that are produced from ROCCO and the combustion of the waste oil from the original lubricant system (see fig. 4-1). The emissions from the combustion of the waste oil from the original lubricant system is however about ten times larger than the emissions from the combustion of the sludge from ROCCO. The combustion of the waste oil stands for about 90 percent of the carbon dioxide equivalent emissions from the original lubricant system, while the combustion of the sludge stands for about 72 percent of the emissions from the system where ROCCO are installed under the conditions modelled in this example.

4.3 **ACIDIFYING POTENTIAL**

The process that contributes with the largest sulphur dioxide equivalent emissions from the system with ROCCO installed are the combustion of the sludge that stands for 59 percent of the sulphur dioxide equivalent emission from this system. The largest contributing process from the original system are the combustion of the waste oil and contributes with 79 percent of the sulphur dioxide equivalent emissions. Emissions from combustion of waste oil from the original lubricant system are again ten times larger (see fig. 4-2) than the emissions from the combustion of the sludge as it is the same processes that contributes to the largest emissions as for the carbon dioxide equivalent emissions.

4.4 **HUMAN TOXICITY POTENTIAL**

The largest contributor to 1,4-Dichlorobenzene equivalents after the installation of ROCCO as well as before the installation are production of the lubricant oil, and stands for 36 percent and 51 percent of the total emission of 1,4-Dichlorobenzene equivalents. The emissions from the production of lubricant oil for the original system is about 17 times larger than for the system after the installation of ROCCO (see fig.4-3). It could be good to keep in mind that no metals that would follow the waste oil or the centrifuge sludge to an incineration facility are included here, as the quantity of metal particles should be roughly the same between the systems.

Figure 4-1. Contribution to global warming from each process category
Figure 4-2. Contribution to acidification from each process category

Figure 4-3. Contribution to human toxicity from each process category

4.5 **Weighting**

Weighting is used to compare different impact categories to each other. For a more detailed explanation of why weighting are used, see section 2. EDIP97 is used as weighting method in this study. An introduction to EDIP97 can be found in section 1.3. In table 4-3 the characterized emissions from both systems are multiplied with the weighting index for EDIP97 (Hauschild et al. 2003, 193) to see which category has the largest environmental impact. In both cases the largest impact comes from the emission of carbon dioxide equivalents. Sulphur dioxide equivalent emissions has the second largest impact from the system with ROCCO installed, whereas the emission of 1,4-dichlorobenzen equivalents has the second largest impact from the original system.
5 INTERPRETATION

In this part the results of the study will be analysed and evaluated. As shown from the previous chapter the original system has a much larger impact in all the impact categories. As the emission of greenhouse gasses has the largest impact of the impact categories it would be a fair to assume that the key parameters for the outcome of the study would be in that category. As the largest part of the emissions of greenhouse gases is emitted when the waste oil from the original system is combusted, whereas the largest part of emissions of greenhouse gases is emitted from the combustion of the centrifuge sludge from the system with ROCCO installed (see fig. 5-1), it seems as these processes is in fact key parameters. If one of these processes would be replaced with another process it could have an impact on the outcome of the study.

<table>
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<tr>
<th>1. Data category for emissions</th>
<th>2. Inventory data for ROCCO (kg/FU)</th>
<th>3. Inventory data for original system (kg/FU)</th>
<th>4. Weighting index EDIP97</th>
<th>5. Total result EDIP97 for ROCCO (2. x 4.)</th>
<th>6. Total result EDIP97 for original system (3. x 4.)</th>
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<tbody>
<tr>
<td>CO₂eq</td>
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</table>

Table 4-3. Weighting of the emission categories

5.1 SENSITIVITY ANALYSIS

As mentioned the outcome of the study could change if re-refining was used instead of combustion for the waste oil the results will be different, see figure 5-2. As the sludge from the centrifuge in the ROCCO system probably are too contaminated and contains too a large part of the separation booster it will not likely be re-refined and will therefore be combusted as in the main example. The re-refining of the waste oil are based on emission data from refining of crude oil (process 2 in appendix II). The emissions of greenhouse gases are in this example 15 percent lower after the installation of ROCCO
compared with 88 percent in the main example. This example is only a rough calculation as data from an actual re-refining process would be preferred to use as it would probably result in some sort of sludge that needs to be handled in some way, for example combustion. But the outcome, that the original system has the largest emissions, will most likely be the same.

Figure 5-2. The outcome of the study regarding global warming potential if combustion of waste oil is replaced with re-refining of the waste oil.

If the oil is combusted, as in the main example, but the ROCCO is powered by German energy mix (Hellberg 2015) (Vattenfall AB 2012) instead of Swedish energy mix, the decrease in carbon dioxide equivalent emission would be about 60 percent (see fig.5-3) after the installation of ROCCO compared with 90 percent for the main example.

Figure 5-3. The outcome of the study regarding global warming potential if German energy mix are used to power ROCCO instead of Swedish energy mix as in the main example.

If the examples in the sensitivity analyses is combined the outcome will be that the ROCCO has about three times larger emissions than the original system (see fig 5-4).
Figure 5-4. The outcome of the study regarding global warming potential if German energy mix are used to power ROCCO instead of Swedish energy mix and the waste oil is re-refined.

6 Discussion

The installation of ROCCO lowered the impact in all impact categories that have been assessed in this paper, for the main model and the processes that has been included. However, as seen in the sensitivity analysis the outcome can be very dependent on which processes the oil goes through during the lifetime of the system. Even though the total impact was still lower for the ROCCO system in the two first examples the difference in impact is not as large as in the main model and in the third example the emissions from the ROCCO system is larger than for the original system. The sensitivity analysis is however kind of an extreme case as some of the waste oil probably are filtered out together with some impurities that has to be taken care of in some way, this means that the environmental benefits of installing ROCCO could be larger than presented in these cases.

Something that could talk in the favour for the ROCCO system, is that the handling of oil decreases if ROCCO, as in this examples, are installed on site and connected to the oil flow of the lubricant system. The handling may not be that big of a problem as the oil used in the examples presented in this paper is quite harmless when handled. But if the oil were highly toxic, like a chlorinated oil, less handling of the oil could be a benefit from a working environment point of view and the risk of mishandling is reduced.

A potential benefit of using the ROCCO system, that has not been assessed in this study is the constantly clean oil in the lubricated machine system. Constantly clean oil means less material waste from the production, due to less particles that can damage the wires, and less wear on the drawing tools during the production of wires. Less material waste could be a great environmental benefit and could potentially be the largest environmental benefit of installing ROCCO. This aspect is not included in this paper due to lack of specified production data from the wire drawing process, an LCA performed on this aspect could however be a good supplement to this LCA.
7 Conclusion

The goal with this LCA was to quantify the difference in environmental impact between the original system and the ROCCO system. The main model covers extraction of oil, refining of oil, production of lubricant oils, additives and separation booster, cleaning of the oil, combustion of centrifuge sludge, waste oil and oil filters and transportation of the oil. The ROCCO system has a lower environmental impact than the original system. The impact in all impact categories was about 90 percent lower than for the original system in the main model and the processes that has been included. The reduction of emissions contributing to global warming potential and acidifying potential are mainly due to the decrease in incineration of waste oil. The reduction emissions contributing to human toxicity potential are mainly due to the decreased production of lubricant oil and that no filter incineration is needed. The global warming potential is the impact category with the, by far, largest emissions. After weighting of the impact categories it is clear that the largest environmental impact comes from the emissions contributing to global warming potential. The reduction of emissions is roughly the same as the reduction in oil use. If the process where the waste oil is incinerated is replaced with re-refining of the waste oil, the reduction of carbon dioxide equivalents would be around 15 percent with the ROCCO system compared with the original system. If the ROCCO were powered by German energy mix the reduction of carbon dioxide equivalents would be around 60 percent and if the ROCCO were powered by German energy mix and the waste oil is re-refined the carbon dioxide equivalent emissions would be three times higher with the ROCCO system compared with the original system.
REFERENCES


[Accessed: 2016-06-06]
Appendix I: Calculations

**Lubricant oil that are needed per FU for the original system**

Oil in the system = 3 m²
Oil changes in a ten-year time = 40
Oil needed = 3 x 40 = 120 m³
Oil needed per FU = 120 x 1,25 = 150 m³

**Lubricant oil that are needed per FU for the ROCCO system**

Oil in the system = 3 m³
Oil recycled per original system oil change interval = 95 %
Oil refilled after 12 weeks = 3 x 0,05 = 0,150 m³
Number of refills in a ten-year period = 39 (4 times per year minus the last 12-week period)
Oil put into the lubricant system including first filling = 0,150 x 39 + 3 = 8,85 m³

**Number of tonnes of crude oil needed to produce the base oil for the production of lubricant oil**

**Original system per FU**

Lubricant oil that is needed to feed the system = 150 m³
Percent of base oil in lubricant oil ≈ 87,6 %
Percent of additives in lubricant oil = 12,4 %
Base oil that are needed to produce 1 m³ of additive = 0,69 m³
Additives needed = 150 x 0,124 = 18,6 m³
Crude oil needed to produce 1 m³ of base oil = 0,94 tonnes
Base oil that is needed to produce 150 m³ of lubricant oil = 150 x 0,876 + 18,6 x 0,69 ≈ 144 m³
Crude oil needed to produce 144 m³ of base oil = 144 x 0,94 ≈ 135 tonnes

**Number of tonnes of crude oil needed to produce the base oil for the production of lubricant oil**

**ROCCO system per FU**

Lubricant oil that is needed to feed the system = 8,85 m³
Percent of base oil in lubricant oil ≈ 87,6 %
Percent of additives in lubricant oil ≈ 12,4 %
Base oil that are needed to produce 1 m³ of additive/booster = 0,69 m³
Additives needed = 8,85 x 0,124 ≈ 1,1 m³
Separation booster needed = 8.32 m³
Crude oil needed to produce 1 m³ of base oil = 0.94 tonnes
Base oil that is needed to produce 8.85 m³ of lubricant oil = 8.85 x 0.876 + (1.1 + 8.32) x 0.69 ≈ 14.25 m³
Crude oil needed to produce 8.5 m³ of base oil = 14.25 x 0.94 ≈ 13.39 tonnes

**Amount of separation booster needed for the ROCCO system per FU**

Oil cleaned per hour = 0.8 m³
Operating hours per year = 4160 (260 days x 16 hour per day)
Oil cleaned per ten-year period = 0.8 x 4160 x 10 = 33280 m³
Separation booster needed per m³ of cleaned oil = 0.25 L
Separation booster needed per ten-year period = 33280 x 0.25 = 8320 L = 8.32 m³

**Electricity use for ROCCO per FU**

Effect of ROCCO = 8 kW
Operating hours per year = 4160 (260 days x 16 hour per day)
Energy used in a ten-year period = 8 x 4160 x 10 = 332 800 kWh ≈ 333 MWh

**Transports for the original system per FU**

Distance to refinery = 538 km
Distance to incineration facility = 690 km
Transported from refinery = 135 tonnes (150 m³ x 0.9 tonne/m³)
Transported to incineration = 135 tonnes
Ton-kilometres = 135 x (538 + 690) = 165780

**Transports for the ROCCO system per FU**

Distance to refinery = 538 km
Distance to incineration facility = 690 km
Transported from refinery ≈ 16.3 tonnes (oil and booster)
Transported to incineration ≈ 16.3 tonnes (oil and booster)
Ton-kilometres = 16.3 x (538 + 690) = 20000
# APPENDIX II: PROCESSES

<table>
<thead>
<tr>
<th>Process</th>
<th>Process name</th>
<th>Database</th>
<th>Literature reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Extraction of crude oil and gas</td>
<td>CPM</td>
<td>Keiserås Bakkene Kristin, Life cycle data for Norwegian oil and gas, 1994</td>
</tr>
<tr>
<td>3</td>
<td>Production of lubricating oil</td>
<td>CPM</td>
<td>Not specified</td>
</tr>
<tr>
<td>4</td>
<td>Production of petrochemical Alcohol Ethoxylates (AE) with 3 moles of ethylene oxide (EO)</td>
<td>CPM</td>
<td>Tenside Surfactants Detergents; 32. Jahrgang 2/1995; Carl Hanser Verlag; Munchen</td>
</tr>
<tr>
<td>5</td>
<td>Combustion of waste oil</td>
<td>CPM</td>
<td>LCI database SPINE@CPM</td>
</tr>
<tr>
<td>6</td>
<td>Oil filter combustion</td>
<td>CPM</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

The figure presents which processes that has been used as references when calculating the emissions from the mass flow. In the column named “process” the reference process is given a number that is used in the text to refer to the reference process. “Process name” is the name of the reference process. In the “database” column the database were the emission data from the reference process is gathered from is presented. “Literature reference” is the source to the emission data presented in the database.