A screening LCA on the recycling chlorinated pilgering oil

Thesis report

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Abstract
In the metalworking industry lubricants are used for production. For production of seamless stainless steel pipes Sandvik Materials Technology uses chlorinated pilgering oil, a lubricant produced from paraffin and chlorine. Today these lubricants are disposed by incineration when the lubricant is too contaminated so production drops, and the lubricant is replaced by new lubricant. RecondOil found a solution to clean these oils instead of disposing them. To assess the environmental impact for the process of cleaning a screening Life Cycle Assessment (LCA) was conducted. The functional unit used is the amount of chlorinated pilgering oil used per year, and impact categories were chosen to be Global Warming Potential (GWP) and Acidification Potential (AP). The study was conducted for the impact from cradle to grave. The outcome of the LCA showed that the main impact for GWP comes from the disposal phase for the conventional process, which is incineration. For the cleaning and reusing process major impacts where found to be from the transportation of raw materials, half-fabricates, products and waste. It was found that only transportation had a major impact on AP. The results show that for both GWP and AP the recycling process has lower potential emissions than the conventional method, but further research on for example electricity and chlorine production is needed to compose a better comparison of the two processes from a life cycle perspective.
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<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>°C</td>
<td>Celsius (degrees centigrade)</td>
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<td>AP</td>
<td>Acidification Potential</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
</tr>
<tr>
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<td>tonkm</td>
<td>tonnes (1000 kilograms) multiplied by kilometres</td>
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1. Introduction

1.1 The product: chlorinated pilgering oil

For the production of metal piping a technique called cold pilgering is used. The machines used for this production need to be lubricated in order to prevent friction. These lubricants are made from oils, which are adapted to meet the criteria for their function. These lubricants get contaminated due to small particles and material spill from the production that get stuck in the oil, and after a certain period of time the lubricants needs to be changed. This is an open loop, since new lubricant is needed after the contaminated lubricant is disposed.

The oil that is studied in this case is chlorinated pilgering oil and is used in cold pilgering machines at Sandvik Materials Technology in Sandvik, Sweden. It is used as a lubricant oil in the machinery that is a part in the production process of seamless stainless steel pipes. Specifically this type of lubricant is used because it can tolerate high pressure and temperatures, which is needed for the circumstances during production. (IARC, 1990) Chlorinated pilgering oil is produced by distilling petroleum and adding gaseous chlorine. (IARC, 1990) Although the product is not directly toxic, it can be carcinogen to humans and other animals, but low amounts of chlorinated paraffin, the main substance of chlorinated pilgering oil, has been found in water, soil or air (IARC, 1990).

1.2 Environmental Relevance

The two ways of resource use and environmental impact of the burning process make this case interesting for environmental concern. The paraffin where the oil is produced from is retrieved from crude oil which is a finite resource, so this resource should be phased out in the future for a sustainable resource. Today, after the oil has been in the metalworking machinery for some time it needs to be replaced due to contamination with particles which decreases its performance and this decreases the productivity of the machinery. This is where the bigger problem shows since chlorinated pilger oil is disposed by burning it in a special hazardous waste burner at over 1000⁰C.

This is where RecondOil comes into the picture. RecondOil developed a method to clean the oil after at a certain contamination level so it can be reused in the machine again, without lower performance than new chlorinated pilgering oil or other complications (Sandvik Materials Technology, 2012). The cleaning can be done in either online continuous cleaning or offline batch cleaning. In this case offline batch cleaning is used, which is a cooperation between Sandvik Materials Technology and Ragn-Sells AB, where the offline batch cleaner will be situated at Ragn Sells in Högbyporpe, Sweden.

There has been a lot of studies about the life cycle of lubricants and oils, but for this particular method only one other life cycle study has been done so far. That study however does not cover the particular chlorinated lubricant discussed in this study.

2. Description of the Case

2.1. The Case

The case that will be looked at in this LCA is a cooperation between Sandvik Materials Technology and Ragn-Sells AB. Today Sandvik has a production line for seamless stainless steel tube production in Chomutov, Czech Republic. Since a few years the lubrication of the machinery has been running on chlorinated pilgering oil that is batch-cleaned by the technology from RecondOil with good results. Sandvik AB also has a production plant in Sandviken, Sweden where the same chlorinated pilgering oil is used in the machinery as in Chomutov. Since the results from Chomutov are good Sandvik AB plans to use batch cleaning for their plant in Sandviken as well. Today the chlorinated pilgering oil is transported to Ragn-Sells AB, a company that sends it further to EKOKEM for destruction and
disposal. Instead it is planned to build an offline batch cleaning system at Ragn Sells AB in Högbytorp where the chlorinated pilgering oil from the production line in Sandviken will be cleaned. This will imply transportation from the metalworking production plant in Sandviken to Ragn-Sells AB in Högbytorp.

2.2 Oil production
For the lubricants oil is extracted in the North Sea. It is assumed that this oil is refined in Germany where it is refined to produce paraffin with carbon chains that consists of 14-17 carbon atoms per molecule. It is then mixed with 50% chlorine between 80-120°C (IARC, 1990) to react to chlorinated pilgering oil. It would be transported by sea and road transport to Sandvik AB in Sandvik, Sweden. This chlorinated pilgering oil is then used in the cold pilgering machines at Sandvik Materials in Sandvik, Sweden. Since the same type of chlorinated pilgering oil is used in both the reference and RecondOils process, the steps from raw material extraction to the use phase are exactly the same.

2.3 Conventional use phase
Today the chlorinated pilgering oil in the cold pilgering machine is tapped off from the machines and transported to Ragn-Sells AB. The machines are filled up with new chlorinated pilgering oil. At Ragn-Sells AB the contaminated chlorinated pilgering oil is sent further to EKOKEM, where it is burned in a special waste burner for hazardous waste. This process runs on high temperatures with special flue gas cleaning to minimize emissions. After the flue gas cleaning the cleaned gases are send through a wet scrubber to clean the gases even more from chlorine. The ashes from this combustion are then put on the landfill for hazardous waste.

2.4 Use phase with RecondOils system applied
If RecondOils system is applied at a certain level of contamination some chlorinated pilgering oil is tapped off the machinery to be send away for cleaning. This results in that the complete volume of chlorinated pilgering oil in the machine is cleaned in a timeframe of a year. The chlorinated pilgering oil is send to Ragn Sells AB in Högbytorp where it is put into a heated sedimentation tank on 80-85°C where a separation booster is added to separate contamination and other particulate matter from the chlorinated pilgering oil. When sedimentation is done after approximately 45 minutes the top 50% of the chlorinated pilgering oil is send for a second sedimentation. The other 50% is filtered from all separation booster, particulate matter and contaminations. About 10% of the chlorinated pilgering oil left in this sludge. The clean chlorinated pilgering oil is send to a last batch and an ester additive is added to adjust the viscosity. After this step the lubricant is ready for transport back to Sandvik Materials Technology to be used again. The high viscose sludge, which is an almost dry substance, is sent to EKOKEM for combustion in the same way as is done with the contaminated chlorinated pilgering oil in the conventional process.

3. Method
The method used is Life Cycle Assessment (LCA). This is a method to assess the potential environmental impact of a product its complete lifecycle. A LCA study is build up in four phases that form the whole study. These are goal and scope definition, life cycle inventory analysis, life cycle impact assessment and interpretation (ISO, 2006). Since this study is based on models and a case that is going to happen in the future, the LCA conducted is a screening LCA.

Main data about processes were retrieved by email conversations with different employees from RecondOil. For data collection the CPM LCI database that is provided by the Swedish Life Cycle Center was used. Distances were approximated by using Google Maps (http://maps.google.com/). This is valid for both sea and road transport.
4. Goal and scope

The goal of this LCA is to assess the potential environmental impacts from the off-site recycling method for chlorinated pilgering oil by RecondOil. To be able to understand the outcome of the study, the conventional method that is used today, was also modelled as a reference. The question that is researched is:

*What impact on the environment do the processes have in form of global warming potential (GWP) and acidification potential (AP)?*

4.1 Functional unit

When defining the functional unit it is important to be able to compare the two cases with each other. A good functional unit could have been based on the production of seamless tube, the product that is made in the metalworking machinery where the chlorinated pilgering oil is used in, but since it was not possible to get hold of the production numbers for seamless tube, this is not possible. Another functional unit could be m$^3$ or tonnes chlorinated pilgering oil, but when this is used the difference in use of chlorinated pilgering oil would not be visible and the impact of both processes could not be compared in a right way. This results in a functional unit of:

*Chlorinated pilgering oil use / year*

4.2 System boundaries

Geographical boundaries are set to Europe. The production boundaries exclude production of machinery that is used during the use phase or for the production of materials or energy, filters, transport, chlorine or additives. The impact of chlorine is excluded since its impact on the impact categories was found to be not significant. Transportation of chlorine gas and additives are not accounted for. Also the impact of disposal of the chlorine is not accounted for. The scope is set from cradle to grave, this means from raw oil extraction to the disposal phase of the product. Since the chlorinated pilgering oil is cleaned or changed every year (Persson, 2016), a time span of 10 years is used so several cleans are done. Even if there is a time span of 10 years, data is retrieved from reports and articles as far back as 1990. Impacts that shown to be lower than 1 equivalent gram per functional unit were not accounted for and are stated as “insignificantly small” in the report. For the technical scope the environmental impacts are calculated for one machine which contains 10 m$^3$ of chlorinated pilgering oil. The oil is changed once per year in the conventional process, or in the case of cleaning, the total volume of the machine is cleaned in a period 1 year (Persson, 2016). Further it is assumed that the oil has a density of 1100 kg/m$^3$, since it is stated in the safety datasheet (Castrol, 2009) that the density is over 1000kg/m$^3$. For calculations it was assumed that the chlorinated pilgering oil consists of 50 mass% chlorine.
5. Life Cycle Inventory

Figure 1 Conventional process flowchart
Figure 2 RecondOils process flowchart
5.1 Description of flowcharts:
This part explains the way of calculating the different emissions and energy use for every single process that is shown above in the flowcharts in Figure 1 and Figure 2. Since step A1 to A7 are the raw material and production phase, these steps imply the exact same processes as in step B1 to B7, which is why these steps are explained together in order to prevent confusion.

AB1 Oil drilling
Raw oil (also called petroleum) is extracted from the oil fields in the North Sea. This emits CO₂ gas, which is 90 kg CO₂ per kg crude oil extracted (Gavenas, Rosendal, & Skjerpen, 2015). Since there is 1.3 kg crude oil needed to produce 1.2 kg of paraffin (Liptow & Tillman, 2009), the CO₂ emissions are multiplied by (1.3/1.2).

AB2 Transport
Transport from the oil extraction site in the North Sea to the oil refinery near Mönchengladbach in Germany. The distance is approximated by picking a point in the North Sea that is close to the coast. From this point the distance by sea to Hamburg Port, Germany is used and further the distance by road is used from Hamburg Port to Monchengladbach, Germany. Sea transport is estimated to be 500 km by a coastal sea container whereas road transport is estimated to be 420 km. This sums up to a total distance of 920 km. For road transport a CO₂ emission of 0,125 CO₂ kg/tonkm (Trafikanalys, 2015) is found for average a truck, whereas transport by sea emits 0,0125 CO₂ kg/tonkm (Blinge, Aranäs, Backström, & Furnander, 1996). SO₂ emissions for sea transport were found to be 0,206x10⁻³ kg SO₂/tonkm (Blinge, Aranäs, Backström, & Furnander, 1996) and for NOx the emissions are 0,26x10⁻³ kg NOx/tonkm. This is based on a coastal fuel tanker. An emission of 0.76x10⁻³ kg NOx/tonkm was found for road transport. (NGM, 1997). Since the data for NOx emissions of road transport comes from 1997, this is not comparable with the NOx emissions from newer trucks that are going to be used in this case. If the emissions from this type of truck (Euro 2) were set to be 100%, a truck that is produced today would emit about 70% of the amount emitted by a Euro 2 class truck from 1997 (EEA, 2016).

AB3 Refining oil
When the raw oil is transported to Monchengladbach, it is distilled in a refinery. To produce the chlorinated pilgering oil that is used in this case, paraffin with a carbon chain length of C14-17 is used (Castrol, 2009). For this process data from a product with similar carbon chain length was used. An emission of CO₂ was found, which is 0,1775 kg CO₂ /kg paraffin produced (Liptow & Tillman, 2009).

AB4 Transport
The paraffin is transported from the refinery to the production site for chlorination. Since the production site for the chlorinated pilgering oil is assumed to be close to the refinery site (<10 km) this step is not accounted for.

AB5a Chlorine production
The chlorine that is added to the pilgering oil can be produced in different ways. These are the membrane process, the mercurery process and the diaphragm cell process. For this study the membrane process was picked since this is the more common used process today. (Euro Chlor, 2015). The process emits 5 kg CO₂ per 1000 kg chlorine, and 2790 kWh of electricity is needed per 1000 kg produced. (European IPPC Bureau, 2000)
AB5 Chlorinated pilger oil Castrol production TDN 50
Chlorine and paraffin are put together in a vessel and this mix is heated up to 80-120°C (IARC, 1990). In this way the chlorine reacts with the paraffin so chlorinated pilgering oil is formed. It is assumed that this process is heated by an electric steam heater. For the energy required to heat these substances the formula $Q = c\Delta T$ is used, where

- $Q =$ heat or energy needed in Joule
- $c =$ specific heat capacity in J/kgK
- $T =$ the difference in temperature in K

The specific heat capacities that are used are 490 J/kgK for chlorine gas and 2130 J/kgK for paraffin oil (Verkerk, 2008). Further an efficiency of 80% was assumed to cover energy losses in the process. A conversion factor of $2.78 \times 10^{-7}$ was used to recalculate from J to kWh.

AB6 Transport
The chlorinated pilger oil is transported to Sandvik Materials Technology from the production site in Monchengladbach. This is approximated by calculating the distance from Mönchengladbach to Hamburg Port and Gothenburg Port to Sandviken by road, and from Hamburg Port to Gothenburg Port by sea transport. For calculation of the different emissions see step AB2.

AB7 Usage in pilger machine
The oil is used as lubricant in the cold pilgering machine at Sandvik Materials Technology. During its lifetime of 1 year it gets contaminated with filler, metal (mainly stainless steel) and other particulate matter. In the machine a filter is used to filter bigger contaminants during production. For the overall process of use no environmental impacts are accounted for since for this study the oil is assumed to be in a closed system.

5.1.1 Conventional process
Continued from A8

A8 Transport
The contaminated and used chlorinated pilgering oil is transported together with filters to Ragn Sells AB in Högbytorp. From this point it is send further to EKOKEM in Norrtorp, Kumla, Sweden for the next step. The complete transport is conducted by road transport. This distance is approximated to be 360 km. For calculation of the different emissions see step AB2.

A9 Combustion
The contaminated chlorinated pilgering oil is burned in special oil burner at 1300°C (Wievegg, 2016). Since the chlorine part is not accounted for, this step is calculated as the contaminated chlorinated pilgering oil is completely incinerated with complete oxygen access, where only the paraffin part is accounted for. According to the safety data sheet (Castrol, 2009) the paraffin that is used has a carbon chain length of C14-C17, where C17 is used for calculations. This calculation results in the amount carbon dioxide emitted to be 1.6 kg CO$_2$ / kg chlorinated pilgering oil burned. Emissions of HCl, NOx and SO$_2$ were found as well, however it showed these have such an insignificant small contribution to the impact categories that these were not accounted for.
5.1.2 RecondOils process

B8 Transport

The contaminated and used chlorinated pilgering oil is transported from Monchengladbach, Germany to Ragn Sells AB in Högbytorp by road transport. This distance is approximated to be 170 km. For calculation of the different emissions see step AB2.

B9 Production of separation booster ORL 06

The separation booster is produced. It is assumed that the separation booster is mainly alcoholetoxylate (Östberg, 2016), and for the production of this chemical a CO₂ emission of 2.233 kg CO₂/kg alcoholetoxylate was found (Verlag, 1995). Since the amount of separation booster was given as a volume percentage of the contaminated chlorinated pilgering oil, a density of 920 kg/m³ (SASOL, 2015) was used to calculate the mass of separation booster that was produced.

B10 Heated sedimentation

This is the first step in the cleaning process. The contaminated chlorinated pilgering oil is first stirred in a sedimentation tank for 30-60 minutes by a stirrer of 2 kW (Persson, 2016) in batches of 1 m³ at a time. To calculate the energy use the formula $E = Pt$ was used, where

$E =$ Electrical energy in kWh
$P =$ Power in kW
$t =$ time in hours

For the calculation the upper limit of 60 minutes used. After 1 hour the stirrer is shut off and the chlorinated pilgering oil is heated up to 80-85°C together with 5 volume% separation booster during 20-24 hours (Persson, 2016). To make calculations the upper limit of 85°C and 24 hours are used. For the calculation of the energy needed for the heating the same formula as in step AB5, $Q = cmΔT$ was used. The specific heating values for the contaminated oil where respectively 1310 J/kgK, which is an average of the heating values for chlorine and paraffin oil used in AB5, and 2470 J/kgK for the separation booster (The Engineering Toolbox, 2016). A loss of 20% energy per hour was used to calculate the complete electricity use. For the electricity a CO₂ emission of 20 g CO₂/kWh was used (Svensk Energi, 2010). After the heated sedimentation the top 50 volume% of the chlorinated pilgering oil is clean enough, so it is send into an after sedimentation tank. The other 50 volume% is send to step B11 together with the contamination and separation booster for filtration (Persson, 2016).

B11 Filtration

The contaminated chlorinated pilgering oil that is not clean has to be filtered from contaminants and the separation booster. The contaminants and separation booster are filtered out of the oil through a vacuum belt filter. A vacuum pump of 2 kW is used to suck the chlorinated pilgering oil through the filter and the chlorinated pilgering oil is kept on 60°C during filtration by an electric steam heater. The residues from filtration (10 volume% chlorinated pilgering oil, contaminations and separation booster ORL 06) are taken care of in step B13. After the filtration the clean oil is send to the after-sedimentation tank by a 2kW membrane pump. (Persson, 2016) Both the earlier mentioned vacuum pump and the membrane pump are assumed to have a flow of 100 m³/hour. For the heating and electricity use the same formulas were used as in step AB5, and the same specific heating values as in step B10.
B12 Filter cake
After the filtration process 10 volume% from the initial amount of chlorinated pilgering oil is left in the residues from filtration. Together with the contaminants and separation booster, this ends up in the form of a dry “filter cake” which has a high viscosity.

B13 Combustion
The filter cake is combusted as last disposal. Ashes go on a landfill for hazardous waste. For this step it is considered that only the incineration of the chlorinated pilgering oil in this filter cake contributes to CO₂ emissions. For calculation of these emissions see step A9. Emissions of HCl, NOx and SO₂ were found but proved to be insignificantly small to account for.

B14 Ester additive CA 653-01 production
To adjust the viscosity of the filtered oil an ester additive is added, this is produced by Castrol. For this step really low emissions were found that contribute to the different impact categories. (McGraw Hill, 2000). This means that due to the low emissions this step is considered to not have any emissions.

B15 Filtered oil
After the chlorinated pilgering oil has been filtered, the ester additive CA 653-01 is added in the after sedimentation tank (Persson, 2016)

B16 Finished product
After the ester additive is added and the chlorinated pilgering oil is clean and has the right viscosity, the chlorinated pilgering oil is ready to be transported to Sandvik Materials Technology in Sandvik, Sweden.

B17 Transport
The finished product, cleaned chlorinated pilgering oil, is transported back to Sandvik Materials Technology in Sandvik, Sweden to be used in the cold pilgering machines. For calculations of this step see step B8.

6. Results
The results are shown in the figures below. Figure 3 and Figure 4 show the Global Warming Potential and Acidification Potential for both lifecycles for the functional unit of chlorinated pilgering oil use / year. From Figure 3 it can be derived that the Global Warming Potential for the conventional process is over 6 times larger than the process by RecondOil. Also the Acidification Potential is over 5 times higher for the conventional process than the process that RecondOil uses.
In Figure 4 the Acidification Potential (AP) is shown for the complete lifecycles. It was found that only the transportation phases in both processes contributes to this impact category.
For the transportation total Global Warming Potential can be seen in Figure 5. It shows that the conventional method has Global Warming Potential of 4 to 5 times higher than RecondOils process.

Figure 6 shows the oil use the emissions shown in the other results are based on. From the chart it can be derived that the chlorinated pilgering oil use is about 5 times higher for the conventional process that for RecondOils process.
In Figure 7 the Global Warming Potential shows a difference of 10 times in kg CO$_2$-eq / oil use per year, which shows the difference in way of disposal and how the amount of oil disposal plays a role in the Global Warming Potential.

Figure 8 represents the use of electricity. The RecondOil process uses more electricity in different parts, while the conventional process uses only electricity for the chlorine production. Since chlorine production uses a lot of electricity the conventional process uses more electricity due to the mass of chlorine needed.
<table>
<thead>
<tr>
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<th>CO2</th>
<th>SO2</th>
<th>NOx</th>
<th>GWP</th>
<th>AP</th>
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<td>kg/FU</td>
<td>kg/FU</td>
<td>kg/FU</td>
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Figure 9 Overview of emissions and impacts for RecondOil process.

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Figure 10 Overview of emissions and impacts for the conventional process.

7. Discussion

The results above show the difference in factors as Global Warming Potential, Acidification Potential and chlorinated pilgering oil consumption. These differences mainly depend on the amount of chlorinated pilgering oil used, and how it is disposed. Until step AB7 the potential impacts on global warming as well as acidification only depend on the amount of chlorinated pilgering oil used in each process, since the process for production is exactly the same. After the use phase in the machines the processes differ in how they contribute to the different impact categories. For the RecondOil process electricity is used for machinery and other purposes to clean the oil, where in the conventional process no use of electricity was considered. When electricity produced in Sweden is used the impact of electricity use on Global Warming Potential is 1% of the total contribution from the lifecycle. Also by comparing the Figures 3, 5 and 7 it can be seen that the transportation and
disposal of the filter cake are the main contributors to the Global Warming Potential for RecondOils process, and that the electricity is not the main contributor.

However, further research would be needed to assess other impacts of electricity use. Even if electricity does not contribute too much to the impact categories considered in this study, the way the electricity is produced can have other environmental impacts. Since the mix of Swedish electricity mainly exists of hydro and nuclear power (Svensk Energi, 2010), these are two contributors to other environmental impacts. Hydropower impacts the biodiversity in the streams and lakes, and reduces the possibility for fish to find food or even to be able to reproduce. (Svensk Energi, 2010). Even nuclear power has an influence on the biodiversity since it uses seawater as a coolant, emitting water that is about 10°C warmer than the initial temperature. Nuclear power also brings a risk with big consequences in case of an accident, and even daily it emits some radiation and the radioactive waste is also a problem for disposal (Svensk Energi, 2010). If in this case the electricity would have another mix of sources, for example an electricity mix with a lot of coal energy used, this would have an influence on the Global Warming Potential since this emits greenhouse gases.

Overall the results show that the cleaning process has a lower impact on the studied environmental impact categories, but it also shows that uses less of the chlorinated pilgering oil. It could be stated that this contributes to a more sustainable way of chlorinated pilgering oil use. This is also the main reason why the emissions are lower for transport or other processes, since it is connected to the amount of chlorinated pilgering oil used.

From the perspective of the study the chlorine part does not contribute too much to the chosen impact categories. This depends on the burning process in the disposal phase, since it is mainly recaptured into road salt. This however can have impact on soil and water, but that is not included in the system boundaries of this study.

From a technical perspective the cleaning of the chlorinated pilgering oil did not have any performance issues compared to new chlorinated pilgering oil. Different types of analyses of the new and cleaned chlorinated pilgering oil did not show major differences, and the production line in Chomutov, Czech Republic proved this by not showing reduced performance of production of seamless stainless steel pipes over a period of 10 years (Sandvik Materials Technology, 2012) (Östberg, 2016).

8. Conclusion
The difference in the use of chlorinated pilgering oil shows a difference in impacts on the Global Warming Potential (GWP) and Acidification Potential (AP). The use of electricity in RecondOils process does not have a major contribution on the two impact categories compared to the other steps in the process in order to be a major environmental threat from the study’s perspective. From the perspective of the impact categories chosen for this study, Recondoils recycling process shows a lower potential impact than the conventional process.
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