6.13 A comparison of repaired, remanufactured and new compressors used in Western Australian Small and Medium-sized Enterprises in terms of global warming

V. Duong[1], W.K. Biswas[2], P. Fray[3] and M.N. Islam[1]

[1] Department of Mechanical Engineering Curtin University, Western Australia, [2] Sustainable Engineering Group, Curtin University, Western Australia, [3] Recom Engineering, Perth, Western Australia

Abstract

Repaired compressors are compared with remanufactured and new compressors in terms of economic and environmental benefits. A detailed life cycle assessment (LCA) has been carried out for compressors under three manufacturing strategies: repaired, remanufactured and new equipment. LCA of global warming potential of repaired compressors varies from 4.38 kg CO_2-e to 119 kg CO_2-e, depending on the type of components replaced. The repaired compressor replaced with carbon- and energy-intensive stainless steel produces 20–25 times more greenhouse gas emissions than compressors repaired with oil pump and terminal block replacements. While GHG emissions from the remanufactured compressors (110–168 kg CO_2-e) are relatively higher than the repaired ones (4.4–119 kg CO_2-e), a new compressor has been found to produce a large amount of GHG emissions (1,590 kg CO_2-e) compared to both repaired and remanufactured compressors. Repairing end-of-life compressors has thus been found to offer end users both dollar and carbon savings in contrast to remanufactured and new compressors.

Keywords:

End-of-life product, life cycle assessment, global warming

1 INTRODUCTION

This paper compares the economic and environmental implications of repaired, remanufactured and new compressors. It focuses on the manufacturing processes of refrigeration and air conditioning compressors.

With the increase in world's consumption of household and industrial products, there is a need to reduce the consumption of mineral resources and the amount of waste generated and end-of-life products sent to scrap yards. To implement this resource efficiency objective, recoverable manufacturing systems could be used. These include repair and remanufacturing, which differ in key control aspects [1]. The environmental performance of repair and remanufacturing was carried out using a detailed life cycle assessment (LCA) analysis.

LCA has been widely used to analyse the environmental benefits of the replacement of a new product with an end-of-life product. The most detailed LCA remanufacturing study to date was on the remanufacturing of photocopiers at Fuji Xerox Australia, internal combustion engines, electrical appliances, gear boxes and compressors [2, 3, 4, 5, 6, 7].

This paper provides options for choosing repairing, remanufacturing or purchasing new for reducing the carbon price. It demonstrates that repaired compressors can perform as well and as long as remanufactured and new compressors within the first three years of the compressor's life. Performance depends on the type of fault in the air-conditioning compressors and that the repairs are of the highest quality.

This research considers a 'cradle to gate' assessment of compressors. This means that the LCA does not take into account product use and disposal, including factors such as recycling and recovery, which would offset carbon emissions and hence the carbon price. The LCA includes only global warming impacts which can be directly attributed to a repaired compressor and the production of a remanufactured compressor and a new compressor.

2 METHODOLOGY

LCA has been carried out to assess the carbon saving benefits of a repaired compressor over remanufactured and new compressors.

The LCA analysis follows ISO14040-43 guidelines [8] in four steps:

1. goal and scope definition
2. inventory analysis
3. impact assessment
4. interpretation.

2.1 Goal and scope

The goal of this LCA is to determine and compare the economic and environmental implications of repaired compressors with remanufactured and new compressors. The compressor used in this case study is a 20 HP Bitzer compressor for refrigeration and/or air conditioning. This paper determines the difference in the carbon footprint (greenhouse gas emissions) associated with repairing compressors and remanufacturing them. These results will also be compared against the carbon footprint of new (original equipment manufacturer) compressors to demonstrate the carbon and cost savings.

There are some limitations that determine the scope of this LCA analysis. First, the analysis only took into account repairs that are of A+ quality (as good as new with 2 year of product starts). This quality is not always achieved, with some repairs being of lower quality. Second, refrigeration and air conditioning compressors are inherently reliable and can survive in service for decades. In Recom Engineering's experience, a mean time to failure for a compressor is 15 years. Third, this analysis is only based on the GHG emissions associated with repairing, remanufacturing and producing new refrigeration and air conditioning compressors. Other than global warming or GHG emissions, no other environmental impacts have been estimated for this LCA analysis.

2.2 Life cycle inventory

A life cycle inventory (LCI) considers the amount of each input and output of different stages of a product's life cycle, and is a necessary initial step in a LCA analysis. An LCI was constructed that includes all inputs involved in the repairing of a compressor in a specific scenario, where the scenarios vary with the number and type of parts replaced and the type of repairing and machining operations.

The LCA of a repaired compressor is better described as preventative maintenance and/or when the compressor has had a minor failure. After the failed compressor has been cleaned and prepared for repair, the repair process involves replacing the damaged components that were removed during the disassembly stage. These may be remanufactured parts (valve plate, terminal block) or new components (oil pump, shaft seal). Table 1 shows the differences between repairing and remanufacturing operations in order to clarify the environmental implications of these two recovery or reuse operations.

The benefit of repair is that it is on site. There is no need to disassemble the compressor and transport it to another location, and this saves on time, money and, most importantly , carbon savings. Repairing a compressor involves:

- inspection and diagnostics: once a failed compressor has been inspected and the problem is deemed repairable, the repair can commence; inspection and diagnostics are done by hand which can take 30 minutes to an hour
- part disassembling: after inspection the faulty part is detached from the compressor using hand tools; this can take 1–2 hours
- minor cleaning and washing: the faulty part or component is removed and cleaned to remove any dirt and debris. Universal flushing agents are used for the cleaning of the compressor and for the remanufacturing of valve plates and terminal blocks. Chemicals such as alkalis, phosphoric acid and decarboniser were mixed with hot water for cleaning and washing operations.

Repairing involves machining a part or component to be remanufactured. For example, in 80% of cases, valve plates are remanufactured which requires cleaning and then removing the broken reeds. The valve plate is then machined using a surface-grinding machine.

Part reassembling involves simply reassembling the compressor with a new part or a remanufactured valve plate or terminal block. This is done with hand tools or an electric impact gun.

Figure A1 in the Appendix shows a detailed version of the LCI of a repaired compressor. It shows the inputs and outputs associated with the processes and the steps that a failed compressor goes through to be returned to service.

Table 1: Differences between the repairing and remanufacturing processes

STAGES	Repair	Remanufacture
Stage 1: disassembly	Disassembly of the faulty component/part is manually done.	The whole compressor is stripped down, using an electric- or air-powered rattle gun. The energy used during cleaning and machining is approximately 13.5 MJ.
Stage 2: cleaning and washing	Minimal cleaning and washing with repairs done onsite, using a universal cleaning agent (200 mL) to wipe down the surface that is being repaired..	Most components, as they are reused, are thoroughly cleaned and washed with a variety of chemicals, using approximately 10.5 MJ.
Stage 3: machining	There is usually no machining during a repair, depending on the part; in some cases valve plates need to be remanufactured, requiring only minor cleaning, washing and surface grinding (4.23 MJ).	Parts that can be remanufactured and reused are often machined to ensure that they are useable; machining includes polishing, surface grinding and rewinding, using a total energy of 114.8 MJ.
Stage 4: part replacement	Components are usually replaced as necessary with new parts during repairs. .	Most components are reused and components that are worn out are replaced with new components.
Stage 5: Assembly	Reassembly is onsite using hand tools or manual labour.	All components are reassembled using an air gun and hand tools, using 13.5 MJ.

Note: The data on energy consumption were obtained from Recom Engineering, Perth, Western Australia.

2.3 Life cycle impact assessment

The carbon footprint of a repaired compressor has been measured in terms of GHG emissions. From the energy and material data in the LCI, the GHG emissions have been calculated and converted to CO_2-e. Simapro 7.2 software [9] has been used to calculate these GHG emissions from paired compressors. The result will also be compared with the carbon footprint of remanufactured and new compressors [7]. The input and output data of different stages from the LCI were used in the Simapro7.2 software. This allowed the GHG emissions to be calculated for the repair of refrigeration and air conditioning compressors. These inputs and outputs are linked to relevant Simapro 7.2 libraries which are databases of energy consumption, emissions and materials data for the production of one unit of a product. The units of input and output data from the LCI depend on the units of the relevant emission database in the software or its libraries [7].

Since local chemicals were used for cleaning and washing, the libraries from the Australian LCA Database [10] for these chemicals were used for the analysis. The main chemicals used were phosphoric acid, thinner, decarboniser, alkali and penetrene. Phosphoric acid was available on the Simapro databases, whereas sodium carbonate (alkali), thinner (methyl ethyl ketone) and decarboniser (dimethlamine) were obtained from the Eco-invent database [11] because they were unavailable in the local database [10]. Penetrene is used in both the repairing and remanufacturing process and its data was available neither on the Simapro database nor in the literature. Penetrene is comprised mainly of petroleum distillate and tetrachloroethylene, so the energy consumption values of these chemicals were used to estimate the approximate emission factor of penetrene.

Recom Engineering is a Western Australian company which disassembles, cleans, washes, machines, reassembles and tests parts and equipment. Therefore, the Western Australian electricity mix has been considered for calculating GHG emissions. Repairing requires the replacement with new components and so the emissions for the production of these new parts were estimated by summing all GHG emissions from mining, processing, foundry and assembling processes. Transport is by truck and van with an average distance of 10 0km. The unit for transport is tonne-kilometre travelled (tkm).

3 RESULTS AND DISCUSSION

Carbon saving benefits: The carbon saving benefits have been calculated for these scenarios:

Scenario 1: Repairing with valve plate replaced

Scenario 2: Repairing with oil pump replaced

Scenario 3: Repairing with terminal block replaced.

The carbon footprints of repaired compressors are 4.4 kg CO_2-e, 6.7 kg CO_2-e and 119.5 kg CO_2-e for the three scenarios, respectively. Scenario 3 produces 12 and 27 times more GHG emissions than scenario 1 and 2, respectively. This is because the valve plate that was replaced with the new one in scenario 1 was comprised of stainless steel, which is a very energy intensive material consuming 108 times more energy than normal steel (Figure 1).

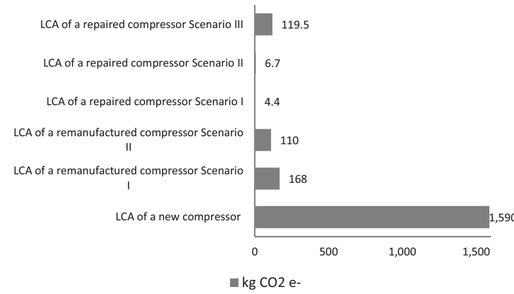

Figure 1: The carbon footprint of repaired, remanufactured and new compressors (Note: the information on remanufactured and new compressors were taken from Biswas and Rosano (2011).

The carbon footprint of the same size (20 HP Bitzer) repaired semi-hermetic reciprocating compressor was compared with the carbon footprint of a remanufactured compressor and a new compressor (Biswas and Rosano 2010). The production of a new compressor would result in a total of 1590 kg CO_2-e, while the remanufactured one would produce 110–168 kg CO_2-e.

Table 2 shows that GHG emissions could be mitigated by replacement of remanufactured and new compressors with a repaired compressor. The repaired compressor in scenario 1 produced 29% and 92.5% less GHG emissions than the remanufactured compressor in Scenario 2 (with 96.5% of total parts reused) and a new compressor, respectively, but produces 8% more GHG emissions than scenario 1 (with 99% of the total parts reused). As explained before, the replacement of a valve plate with the new one, which is made of energy intensive stainless steel, increased the GHG emissions significantly. The repaired compressor in scenario 2 (with oil pump) has produced 94%, 96% and 99.6% less GHG emissions than those of remanufacturing scenarios 1 and 2 and a new compressor production, respectively. The repaired compressor in Scenario 3 can mitigate 96%, 97.4% and 99.7% of the total GHG emissions by replacing remanufacturing scenarios 1 and 2 and the production of a new compressor, respectively. Thus, repairing is less energy intensive and produces lower GHG emissions compared to remanufacturing or the production of new compressors.

Table 2: GHG emission mitigation due to replacement of remanufactured and new compressors with repaired compressors

Repairing scenario	GHG emissions mitigation		
	Reman scenario 1	Reman scenario 2	New
1	-8%	29%	92.5%
2	94%	96%	99.6%
3	96%	97.4%	99.7%

Scenario 1 (minimum part replacement): Ninety-nine per cent of the parts (on the basis of weight) were reused by cleaning, washing and machining, and less than 1% were replaced with new parts.

Scenario 2 (maximum part replacement): Ninety-six and a half per cent of the total parts were reused and the rest were replaced by new parts.

When the use (or operation) stage is included, the additional GHG emissions would be 189,000 kg of CO_2-e, which is significantly higher than the emissions from the manufacturing stage.

In most of the repairing of the compressor, replacement accounts for a significant portion of the total emissions, followed by repairing and machining. For Scenario 1, 95%, 3%, and 2% the GHG emissions result from replacement, machining and repair. These values for scenario 2 are 62%, 20% and 18%, respectively. For scenario 3, 49%, 30% and 22% of the total GHG emissions result from replacement, machining and repair. Therefore, replacement activities need to be avoided especially for high energy intensive materials, those associated with processing and manufacturing of the valve plate. In all cases, machining and repairing produce a very small portion of GHG emissions compared to replacement.

Economic benefits: Since repairing emits less CO_2-e, the the carbon tax will be reduced in the current Australian carbon pricing scheme. If the price of carbon were set at $25 per tonne of CO_2-e, a new compressor which emits 1.590 tonnes of CO_2-e equates to an additional cost of $39.75. Repairing scenarios 1, 2 and 3 would have an additional cost of $2.98, $0.20 and $0.10, respectively. Remanufacturing scenarios 1 and 2 have an addition cost of $2.75 and $4.20, respectively. In the case of a 20 HP Bitzer semi-hermetic reciprocating compressor, the estimated cost of repaired compressors (A$1000) is 73% less than a remanufactured compressor (A$3752) and 82.4% less than purchasing a new compressor (A$5686) (Peter Frey 2011, pers. comm., Recom Engineering, Perth).

4 CONCLUSION

Repairing as the main option for the management of end-of-life products can help reduce the stress on natural resources, and can also be economically and environmentally beneficial. Repairing compressors can potentially reduce the GHG emissions associated with a remanufactured or new compressor. About 29% to 97% of the total GHG emissions can be mitigated by replacing a remanufactured compressor with a repaired compressor, and a maximum of 99% of the total GHG emissions can be mitigated by replacing with a new compressor. Repaired compressors are cheaper than both remanufactured and new compressors and conserve non-renewable mineral resources for future generations.

[1] Guide, V.D.R., Srivastava, R., 1997, Recoverable Manufacturing Systems: A Framework for Analysis. Innovation in Technology Management - The Key to Global Leadership, Portland International Conference on Management and Technology, 675-78.

[2] Kerr, W., Ryan, C., 2001, Eco-efficiency Gains from Remanufacturing A Case Study of Photocopier Remanufacturing at Fuji Xerox, Australia, Journal of Cleaner Production, 9: 75–81.

[3] Kondo, Y., Nakamura S., 2004, 'Evaluating Alternative Life-Cycle Strategies for Electrical Appliances by the Waste Input-Output Model, International Journal of Life Cycle Assessment, 9 / 4 : 236-246.

[4] Shi-can, L., Pei-jing S., 2004, Benefit Analysis and Contribution Prediction of Engine Remanufacturing to Cycle Economy, Journal of Central South University of Technology, 12/2: 25-29.

[5] Smith, V.M., Keoleian, G.A., 2004, The Value of Remanufactured Engines Life-Cycle Environmental and Economic Perspectives, Journal of Industrial Ecology, 8/1-2: 193-221.

[6] Kara, H., 2009, Carbon Impacts of Remanufactured Products, Gear Box (6 Speed Automatic). Centre for Remanufacturing and Reuse, Aylesbury, UK.

[7] Biswas W. K., Rosano, M., 2011, A Life Cycle Greenhouse Gas Assessment of Remanufactured Refrigeration and Air Conditioning Compressors, International Journal of Sustainable Manufacturing (IJSM) 2/2-3:222-236

[8] ISO, 1997, Environmental Management – Life Cycle Assessment – Principles and Framework, ISO 14040, International Organization for Standardization (ISO), Geneva

[9] PRé Consultants, 2008, Simapro Version 7.1, The Netherlands.

[10] RMIT, 2005, Australian LCA Database 2005, Centre for Design, Royal Melbourne Institute of Technology, Victoria.

[11] SCLCI, 2007, The Ecoinvent Database, Swiss Federal Laboratories for Materials Testing and Research, Switch Centre for Life Cycle Inventory, Zurich, Switzerland.