ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil


# METHOD TO CALCULATE THE RECYCLABILITY RATE OF AGRICULTURAL MACHINERY DURING THE DESIGN PHASE

**Leoni de Souza Leite**
University of Campinas – UNICAMP
Faculty of Mechanical Engineering
Department of Mechanical Design
PO Box 6122
13083-970, Campinas/SP, Brazil
leonileite@hotmail.com

**Niederauer Mastelari**
University of Campinas – UNICAMP
Faculty of Mechanical Engineering
Department of Mechanical Design
PO Box 6122
13083-970, Campinas/SP, Brazil
niede@fem.unicamp.br

***Abstract.*** *Integrating the environmental aspects with the product development involves many strategic objectives related to the product. The design of product can incorporate features that make it more suitable to be reused or recycled. An agricultural machine can have a system composed by subsystems, which ones must operate, presenting a specific performance to keep operational conditional according to the design requirements. The materials of these components presented subsystems that cannot contaminate people and environment. In the agricultural machine sector there are few studies and bibliographies that relate about this research. Agricultural machine manufacturers look for information in automotive and electronic areas to adapt their needs. This paper shows a method to calculate the rate of the agricultural machine recyclability using as international reference standards. After calculating the rate of recyclability yet in the phase of product development, we can suggest materials alterations and also in the configuration of the subsystem following, the objective to increase the rate of recyclability and minimize the environmental impact. This paper made use of an agricultural sprayer available in the market to calculate the rate of recyclability.*

***Keywords:*** *recycling, recyclability, agricultural machine, environment, sprayer*

## 1. INTRODUCTION

After the 1940's Brazilian companies have excelled in the manufacture of agricultural implements. A Brazilian company was the first to develop and patent in Brazil a sprayer that was a duster. Another Brazilian company has developed a planter and fertilizer that did not have to use animal force to move around (ABIMAQ, 2012).

Every decade the agricultural machinery sector stands in growth rates and new technologies are incorporated in these products.

According to ABIMAQ (2013), the agricultural implements industry presents good growth rates in recent years. The agricultural implement industry ended the year 2012 with gross revenue of R$ 11.2 billion, resulting in a 13% increase over the previous year's performance.

Also growing is the search for products that do not pollute the environment or minimize this risk (SRIVASTAVA, 2007).

The growing environmental concern and the structuring of sustainable business drive the development of products that cause less impact on the environment. The environmental impacts of contaminated products, such as tires, lights, batteries, pesticide containers, are already well known.

As Bertolini (2011) says, some companies adopt a selection policy at the time of purchasing raw materials and environmentally friendly products, making your product also environmentally friendly. There are companies that during the manufacture process manage all stages of the production cycle of the product in order to minimize the impact to the environment. We also have companies that care about the disposition of your product after use by the final customer and advise on the best way of disposal or recycling the product after use.

Ballou (2006), describing the supply chain, says it is a set of functional activities that are repeated numerous times throughout the flow, in which the product passes from the first stage to the end point consumer sale. The term supply chain represents the interconnection of organizations, forming a "chain", in which each link (company) is responsible for its stage (activity). In this point of view, the supply chain, unfolds from the raw material, in a primary stage,

ISSN 2176-5480




undergoing several transformations until it reaches the final customer. Every stage that moves, turns, adds up value and it is projected in a finished product that meets the needs of the final customer.

According to Bertolini (2011), environmental issues are considered in different ways by society: government, NGOs, businesses and consumers. Governments and NGOs seek to collaborate and claim so that the environmental impacts caused mainly by companies become smaller. Consumers have a different view of others. It is noted that the government, NGOs and companies have directed their actions to the process, and consumers circumscribing, in most cases, to the product.

ISO 17314 (2008) says that machinery and equipment at the end of the productive life contribute to the total amount of waste to be treated. As part of the life cycle of the machine, it is essential to consider recycling during the design phase, to ensure environmentally correct treatment. Currently, when designing a machine, you should consider recycling as well as safety, emissions and fuel consumption. Consequently, it is necessary an indicator to assess the capacity and potential of new machines to be recycled or recovered.

In this paper, it is proposed a quantitative method for calculating the recyclability rate. The recycling of the product is quantified as "recycling rate" defined as the mass fraction of recyclable materials to the total mass of the product. Considering this recyclability rate, still at the stage of product development changes in materials and subsystem configuration can be suggested, with the goal of increasing their recyclability rate and minimize environmental impact.

In the agricultural machinery sector there are few studies and bibliographies that treat the research topic. Agricultural machinery manufacturers seek information from the automotive and electronics to accomplish with their needs.

The purpose of this paper is present a method to calculate the recyclability rate of an agricultural machine during its design phase using the international standards as reference. So it is proposed a quantitative method for calculating the recycling rate. The recycling of the product is quantified as "recycling rate" defined as the mass fraction of recyclable materials to the total mass of the product

After calculating the rate of recyclability yet in the phase of product development, we can suggest materials alterations and also in the configuration of the subsystem following, the objective to increase the rate of recyclability and minimize the environmental impact.

## 2. LITERATURE REVIEW

### 2.1 Agricultural Machines

As Mialhe (1996), at the beginning of the agriculture mechanization in the mid-nineteenth century, the machines were considered by some mere curiosity, for others a luxury and, for many, a social calamity. Then, in the years since the passage of the century, began to be accepted as a necessity of modern times, and finally, in the period after World War II, has become a basic requirement for the development of agriculture in many countries, including Brazil. That's when the inevitable happened: first, the international market found itself swamped by occasion products, inoperative machines, defective, of dubious quality, produced by improvised and opportunistic manufacturers; on the other hand, a universe of users is not always sufficiently prepared to select them and make good use of them, but highly encouraged by generous credit incentives and full advertising material. The disastrous consequences soon were present and the reaction of the government of many countries canalized by measures aiming to control the quality of agricultural machinery, hence the birth of numerous testing centers or stations in the peripheral countries. In Brazil the first concrete initiatives aiming the testing of agricultural machines appeared around 1946, just after the end of World War II.

### 2.2 Product Development

With globalization products must present high quality, in the broadest sense of the term, in other words, the product must be competitive. In order to achieve this competitiveness the product must be developed in an integrated manner, with skills in multiple disciplines. Must speak in integrated teams of professionals in different functions within a company, or who work simultaneously throughout the process of product development.

Product development is initiated, planned, executed, controlled and terminated in the form of project management. The management is important for the team of professionals from various skills reach good results. This management action is called management or project management, the *Project Management*.

According to Huston; Sakkab, (2006), the process of product development requires an integrated management involving cross-functional internal capabilities and external partnerships, to enable the company to generate innovations that enable it to monitor the need for growth. Most mature companies need to generate every year, an organic growth of 4% to 6% and how to do it if most of the companies follow clinging to a model of invention centered on a thesis that innovation should primarily come from within the company.

It is related to the management of all activities, to develop a product. Part of the original idea of market needs and technological possibilities and consider the corporate strategies, business and product strategies of the company, until reach the design specifications of a product and its production process. Product development also involves the

ISSN 2176-5480



monitoring of the product after its launch, to make necessary changes resulting from their use and plan their phase out, involving so throughout the product life cycle (ROZENFELD *et al*., 2006).

### 2.3 Eco-design

According to Puglieri (2010), since the beginning of industrial production until the 1950s and 1960s, companies did not adopt emission control practices that aimed to minimize the environmental impacts of their activities. The concept of cleaner production emerged in the following years by adopting a precautionary approach and in order to reduce treatment costs and minimize the environmental impacts of the activities of the production process in companies. At the end of 90 years this vision has expanded to the life cycle and began to be applied in products development, whose main technique was life cycle valuation (LCV). Companies in this new stage of environmental management became known as proactive approach focused on the product, not only to the process.

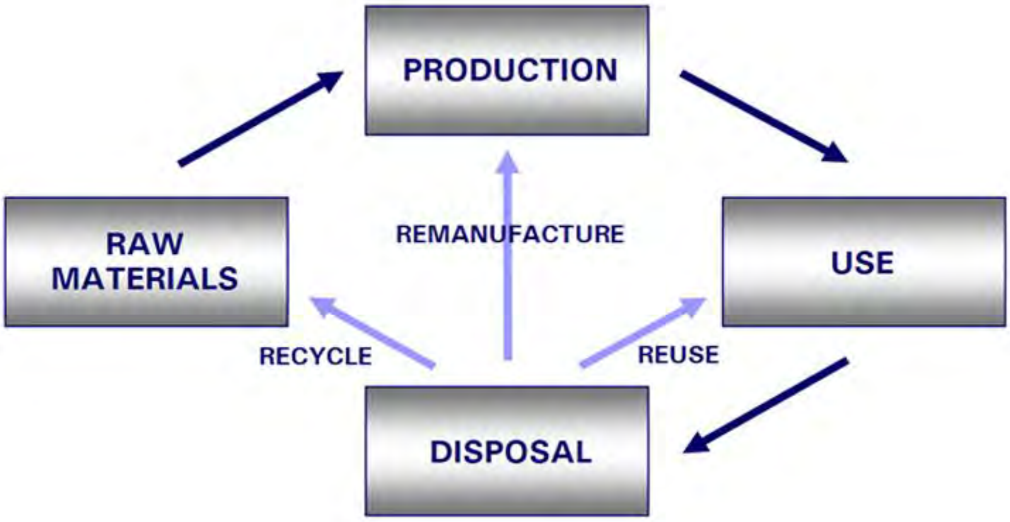



Figure 1. Main phases of product life cycle and flows of resources

Eco-design is to make that the project's environmental activities be oriented from the first step of a product design until its stage of production and consumption. Recently, this last phase has been extended to deal with recycling at the end of product life. The eco-design should integrate environmental criteria in the design and product development. This means balance the environmental requirements with basic project requirements such as cost, quality, safety, once the products are primarily designed to be produced and to be efficiently used by customers, and secondly, to be disassembled and recycled (DE MEDINA, H. 2006).

According to Alves, M. F (2005) the basic assumptions for the Eco-design are presented in Tab. 1.

Table 1. Basic premisses for Eco-design.

| | |
|---|---|
| Ease of disassembly and maintenance | The product should be assembled preferably with non-permanent fasteners (screws, clips, latches etc), avoiding unnecessary and overlapping welds by application of adhesives; in order to facilitate access to components subject to maintenance and replacement. |
| Application of pre industrialized materials | Raw material already industrialized in earlier processes (casting, extrusion, injection, lamination) under the shapes of plates, profiles, tubes, plates, laminates; harnessed to amortize the primary investment in energy. |
| Components standardization | Industrialized common items available in the market and easily visual recognized (containers, lids, hinges, pins, buttons, handles, trims, etc) used as normal components into new products. |

ISSN 2176-5480




| | |
|---|---|
| Closed life cycle | Project aiming the substitution of the discard phase by recycling, reincorporating the product into the production cycle, thereby promoting the reduction of consumption of raw materials, energy and waste. |
| Modularity | Design into modules that can be improved disassociated. A module can serve multiple models of a product line. |

### 2.4. Reciclability

Recycling of materials is increasingly becoming part of our daily life: recycling cans, paper, plastics. European companies such as automobile manufacturers must by law comply with the specific goals of recycling.

As Villalba, G., et al (2002), car manufacturers invest in research on design for disassembly and recycling, in order to meet the recycling targets, not only in Europe but worldwide. For example, the EU directive on end of life vehicles (EU Directive 2000/53/EC, June 2000) puts all the responsibility (economic and physical) to car manufacturers for proper disposal of end of life vehicles. According to this policy, the automotive industries have the following objectives: to January 1st, 2006, 85% in weight of a car should be recycled or reused, of which 5% is allowed for energy recovery, and January 1st 2015, 95% in weight of a car should be reused or recycled, of which 10% is allowed for energy recovery. Since 1992, more than 30 million cars per year are being eliminated.

In Brazil some progress has been observed in the field of analysis of the potential and actual impact of environmental contamination by heavy metals. In addition to the environmental gains achieved by reducing the contamination of soil and groundwater by heavy metals in Waste Electrical and Electronic Equipment (WEEE), an important aspect is to add value to the waste that can result in generating competitiveness in the market (XAVIER *et al*., 2010).

A study by Tanimoto *et al*. (2010) shows that 28% of the copper sold in Brazil is part of the chain of electronic waste. Copper is a noble material, but the study also describes that in Brazil there is no widespread technology for the collection and reprocessing of this material.

According to the UN report from 2009, Brazil generates 0.5 kg of solid waste coming from PCs per capita annually. In addition, sales of computers in the country grow in the double digits. In the first half of 2009, the increase was 20%, reaching 6.2 million units sold by the industry, according to the Brazilian Association of Electrical and Electronics Industry (Abinee). In this scenario, the potential disposal grows enough. There is a need to improve a lot so you can achieve a significant reduction in the environmental impacts caused by the improper disposal of materials from e-waste.

As Tanimoto *et al*. (2010), in Brazil, in line with global trends, the waste flow of electrical and electronic equipment and scrapped vehicles are good prospects as future sources of usable copper. Although it is less than 1% mass, these waste flows contain almost 38% of the copper released into the biosphere. A significant portion of these flows is already part of an informal economy, promoting a market for second hand equipment under demanding specifications of parts and repairs.

Even today, most of the products used was thrown or incinerated with considerable damage to the environment. This is because some manufacturers do not feel responsible for their products after consumer use. Thus, currently consumers and authorities expect manufacturers to reduce the waste generated by their products. Therefore, waste management has received growing attention; due to new legislation which focuses on recycling, because of high costs and environmental burden for disposal. Companies are increasingly responsible for the collection, removal and proper disposal for used products and packaging materials (ADLMAIER; SELLITO, 2007).

Currently, in Brazil, it is regulated the responsibility for the life cycle of the product in the following chains: pesticides, batteries, tires, lubricants and fluorescent lamps. Such regulation may also extend to products marketed in plastic, metal or glass. This regulation may be treated in reverse logistics (LEITE, 2009).

According to Maris, E. *et al.* (2012) the production starting from of recycled materials makes it possible to save about 80% energy compared to needed for processing virgin materials Fig. 2 and prevent significant emissions of greenhouse gases. Recycling of materials from end of life products is essential to preserve the resources of raw materials, which are increasingly expensive and whose extraction is increasingly impacting the environment.

ISSN 2176-5480



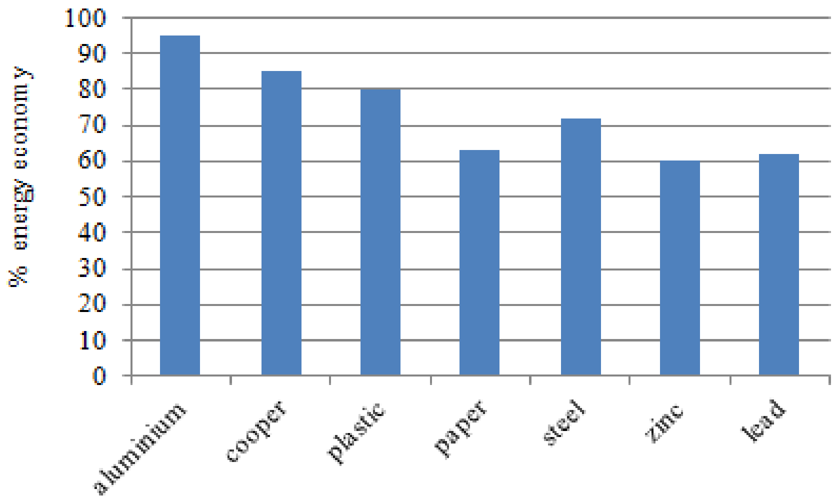



Figure 2. The use of recycled material saves energy compared to the use of virgin material (Maris, E. *et al.,* 2012)

Durable plastics, unlike most of packaging and convenience products that are discarded after a single use, tend to have a life cycle of 3 years or more. Cars, computers, appliances fit into this category. The use of plastics in durable applications continues to grow. The recovery of plastics from such durable goods is complex. Often, they are integrated with various other plastics and non-plastics components. Their separation, recovery and purification require several steps and, in general, quantities of such materials available for retrieval are limited. However, several efforts are under way to explore the recycling of these products after their life cycle. The manufacturers of these products are committed to use recycled materials wherever is possible as a part of the total requirement of the material. Automotive companies have major efforts in recycling plastic components and try to use materials with recycled plastic content (SUBRAMANIAN, PM, 2000).

Recently MARIS, E. et al (2012) said that presence of impurities in polymers because of the poor screening influences the performance of the recycled material. Good quality of the recycled material is necessary in order to find more "noble" solutions and expand the number of opportunities for the use of a high performance material with economic value close to virgin plastic. Studies have shown that improving the recycling of a product is one of the ways to limit environmental impacts and costs of materials.

In the ongoing search for more sustainable practices in manufacturing processes is fundamental to increase society's knowledge about an important feature of steel: it is 100% recyclable. This capacity to return permanently to the productive chain as raw material, without losing the quality makes it one of the most recycled materials in the world. Its transformation meets demands in different sectors such as automotive, construction, machinery and equipment, white goods, cutlery, among others. The environmental benefits related to recycling in the steel industry are extensive, including reducing the use of non-renewable raw materials and reducing emissions of greenhouse gases. There is also a positive social impact, due to job creation in the collection and processing of scrap (INSTITUTE OF STEEL, 2013).

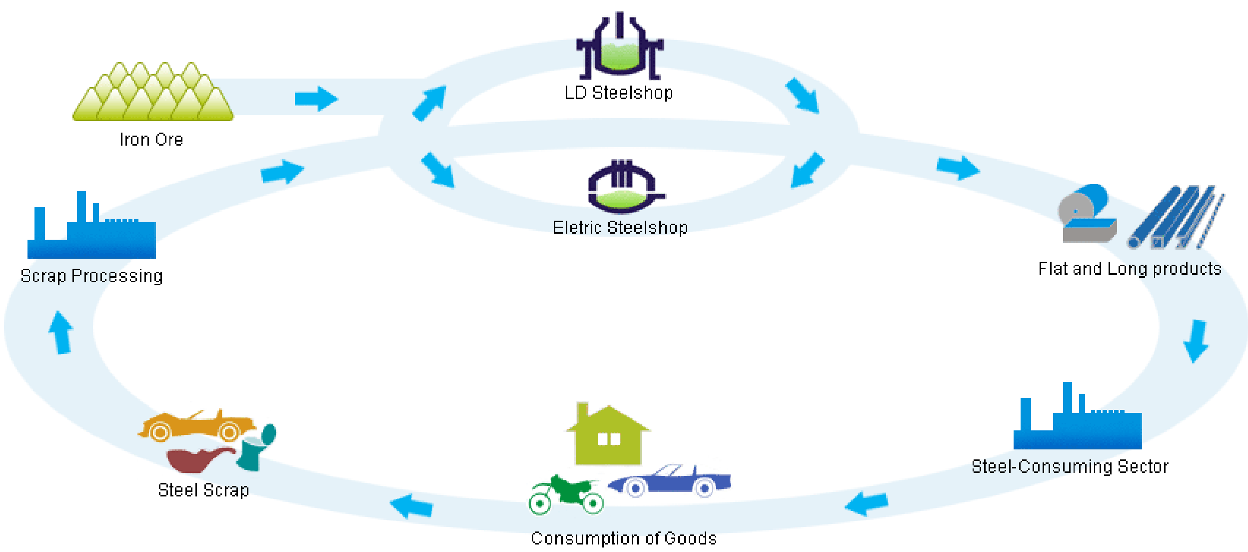



Figure 3. Steel recycling cycle (Institute of Steel, 2013)

ISSN 2176-5480




## 3. Method and materials

### 3.1. Materials

In order to survey the recyclability rate it was used a brand new manual 20 liter capacity knapsack sprayer available in the market, figure 4. One scales, fig. 5 (a), brand Ohaus, Scout Pro from Toledo do Brazil, model SP4020, grade 0,01g, maximum capacity 400g and minimum 0,02 g. Also one scales, fig. 5 (b), brand Filizola, model AS 6000C, grade 0,01g, maximum capacity 6000g and minimum 0,025 g.

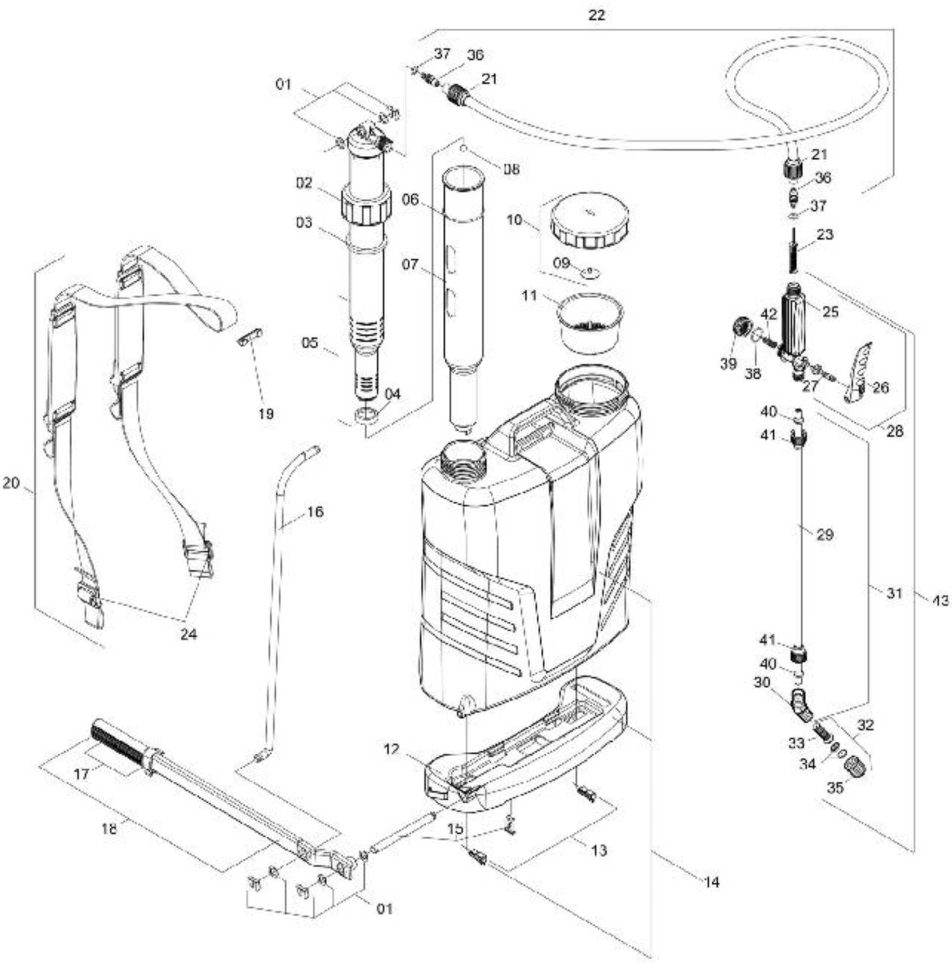
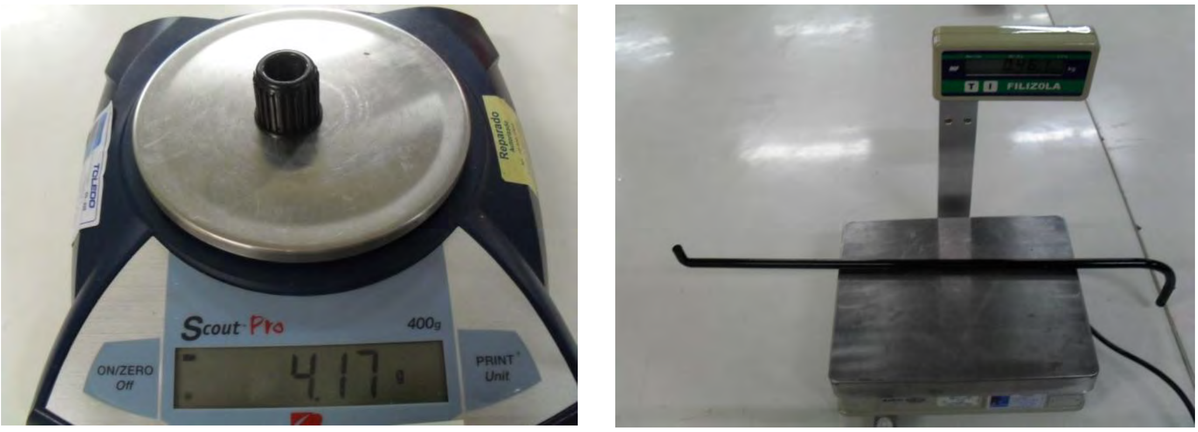



Figure 4. 20 liters capacity Knapsack Sprayer




a) b)

Figure 5. Scales and components weighing, a) component manufactured in polymer and, b) component manufactured in steel

ISSN 2176-5480



### 3.2. Method

For the calculation of recyclability rate of the knapsack sprayer under study was used as a reference ISO 17314 and ISO 22628 standards which establishes the guidelines for the calculation of the recyclability rate during the development phase of the product or when the product is brand new. These standards are a tool of international standard that gives manufacturers a way to assess the capacity and potential of new machinery and vehicles to be recovered and / or recycled. It assists designers to calculate the percentage of reuse and recycling machinery, vehicles, their components and materials before being put on the market.

The calculation of recyclability rates is performed through the following four steps for a new vehicle or machine, to which the components, materials, or both, may be considered in each step: pre-treatment, disassembly, separation of metals and treatment of metallic wastes.

As a general requirement, a component should be considered reusable, recyclable, or both based on their way for disassembly, which is measured by accessibility, technology for fixing and disassembly testified technologies. As a specific requirement, a component should be considered recyclable based on the materials that compose it, and the testified recycling technologies. A component or material must be associated with a recycling technology testified in order to be recyclable. An additional requirement is that the reusability of a component should be subject to security considerations and environmental risks.

Figure 6. Knapsack Sprayer Components

The knapsack sprayer was disassembled on a stand, and the components were weighed on scales.

After weighing the knapsack sprayer components, they were separated and all materials classified in the following categories: metals, polimers, excluding elastomers, others, elastomers.

Table 2 Presents the data after weighing and grading of material.

Where:

***mD*** mass of materials taken into account at the dismantling step.

***mU*** mass Undefined residue.

Table 2. Data Presentation

| **Materials** | **Recycling** ***mD (g)*** | **Waste** ***mU (g)*** |
|---|---|---|
| metals | 992,42 | 0 |
| polimers, excluding elastomers | 2.364,79 | 0 |
| elastomers | 188,53 | 0 |
| others | 0 | 7,14 |

ISSN 2176-5480



For this type of knapsack sprayer there is no need of pre-treatment of components and also there is no reusable components.

Formula used in the calculation of the recyclability rate based in the standard ISO 17314 and ISO 22628.

$$Rcyc = \frac{mD}{mTs} \text{ x } 100 \quad (1)$$

Where:
***mD*** mass of materials taken into account at the dismantling step: 3.623,17
***mU*** mass Undefined residue: 7,14
***m*TS** total mass Sprayer: 3.630,31
**Rcyc** recyclability rate: 99 %

## 4. RESULTS

Considering the obtained results, it can be concluded that the knapsack sprayer has presented a recyclability rate of 99%, being 27.33% metals; 65.14% polymers; 5.19% elastomers.

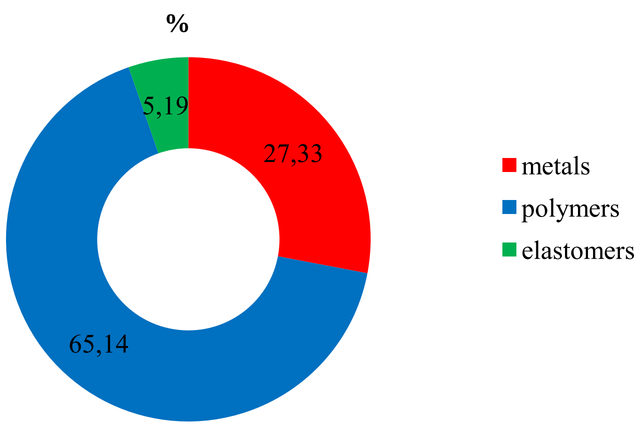



Figure 7. Recyclable materials

Even if a machine has a high recyclability, in other words, has recyclable parts, recycling will only happen effectively when there is technical and economic feasibility.

It is evident that the materials used in the manufacture of the knapsack sprayer are recyclable and can be recycled by existing technologies in the area. The environmental impact is considered low for a machine with 99% recyclability rate, but must respect the laws and regulations in place.

The recyclability rate of 99% for an agricultural machine can be considered appropriate when compared to the goal of 95% published on directive 2000/53/EC and that the automobile industry of the European Union is currently working to meet.

## 5. CONCLUSION

A method was presented to evaluate the recyclability of a knapsack sprayer based on ISO 17314 and ISO 22628 standards.

The equipment was disassembled and their parts classified and heavy. After this data it was obtained an index of 99% recyclability rate.

This method can also be used during product development to guide changes in materials and subsystem configuration, in order to increase the recyclability and minimize environmental impact. This method can also be applied to other agricultural machines such as those used for soil tillage and sowing machines. It should also be observed that machines in their end of life cycle, including the knapsack sprayer used to validate the presented method can generate contaminated waste. At the end of life cycle if the machine is released into the environment without adequate treatment it can cause pollution by toxic substances. Contaminated waste can be classified according to ABNT

ISSN 2176-5480




BNR1004. After classification all contaminated waste must be treated and disposed according to appropriate laws and regulations.

The calculation of the recyclability rate may assist in the development of more sustainable products and environmental preservation.

## 6. REFERENCES

ABIMAQ, 2013. Monthly newsletter of the Sectorial Chamber of Agricultural Machines and Implements ABIMAQ 2013 - Nº 43.

ABIMAQ, 2006. “The History of the Machines - ABIMAQ 70 years”. ABIMAQ - Brazilian Association of Machinery and Equipment. São Paulo, Brazil.

Alves, M. F., 2005. “Automobile project management: critical success factors in product start-up”. Master's Dissertation, University Fluminense.

ADLMAIER, D.; SELLITTO, M. Returnable containers for transportation of manufactured goods: a case study in reverse logistics. magazine Production, v. 17, n. 2, p. 395-406, 2007.

BALLOU, Ronald H., 2006. “Managing the supply chain: logistics business”. Bookman.

Bertolini, G. R. F., Rojo, C. A., & Lezana, Á. G. R., 2012. Investment analysis model for green manufacturing. *Gestão & Produção*, *19*(3), 575-588.

Brazilian Association of Technical Standards (ABNT); Classification of Solid Waste, ABNT NBR10004, Rio de Janeiro, 2004.

De Medina, H., 2006. “Eco-design for materials selection in automobile industry”. In *CIRP international conference on life cycle engineering, 13th, Leuven, Belgium* (pp. 299-304).

HUSTON, Larry; SAKKAB, Nabil. Connect and develop how the new model of innovation procter & gamble. In: *Harvard Business Review*. p. 28-36. mar. 2006.

Brazil Steel Institute. 2013. “Sustainability Report 2013”.

INTERNATIONAL STANDARD ORGANIZATION (ISO). ISO 22628 - Road Vehicles - Recyclability and Recoverability – Calculation Method. Genebra, 2004.

INTERNATIONAL STANDARD ORGANIZATION (ISO). ISO 17314 - Manually portable forest machinery - Recyclability and recoverability - Calculation method, 2008

LEITE, P.R. Reverse Logistics: Environment and Competitiveness. 2nd edition. Sao Paulo: Pearson Pretince Hall, 2009.

Maris, E., Aoussat, A., Naffrechoux, E., & Froelich, D., 2012. “Polymer tracer detection systems with UV fluorescence spectrometry to improve product recyclability”. *Minerals Engineering*, *29*, 77-88.

MIALHE, L. G. 2006, Equipment: testing & certification. Piracicaba: FEALQ, 1996. 723 p.

Puglieri, F. N., 2010. “*Review and analysis of environmental and operational methods ecodesign based QFD and FMEA”*. Master's Dissertation, School of Engineering of São Carlos, University of São Paulo, São Carlos.

ROZENFELD, H. et al (2006). Management of Product Development - A reference to process improvement. São Paulo, Saraiva, 2006.

SRIVASTAVA, S. K.; Green supply-chain management: A state - of the - art literature review. International Journal of Management Reviews, v. 9, n. 1, p. 53–80, 2007.

Subramanian, P. M., 2000. “Plastics recycling and waste management in the US”. *Resources, Conservation and Recycling*, *28*(3), 253-263.

TANIMOTO, A.H.; DURANY, X.G.; VILLALBA, G. E.; PIRES, A.C. Material flow accounting of the copper cycle in Brazil. Resources, Conservation and Recycling, In Press, Corrected Proof, 2010.

The International Organization for Standardization, 2008. “ISO 17314:2008 Manually portable forest machinery - Recyclability and recoverability - Calculation method”.

The International Organization for Standardization, 2002. “ISO 22628:2002 Road vehicles – Recyclability and recoverability – Calculation method”.

Villalba et al., 2002 “A proposal for quantifying the recyclability of materials”. *Department of Chemical Engineering and Metallurgy*, *University of Barcelona.*

XAVIER, L. et al. Management of electronic waste: mapping the reverse logistics of computers and components in Brazil. 3rd Iberoamerican Symposium Ingeniería Waste. 2010.