REFEREED ARTICLE

DOI: 10.5836/ijam/2015-02-07

Material and energy demand in actual and suggested maintenance of sugarcane harvesters

EDEMILSON JOSÉ MANTOAM[1], THIAGO LIBÓRIO ROMANELLI[2] and MARCOS MILAN[3]

ABSTRACT

Since green revolution agriculture has provided more yield *vis-à-vis* more energy demand. Currently, in the search for bioenergy, Brazilian sugarcane has gained attention, but as an energy source its efficiency has to be monitored. Energy balance is the physical evaluation of required inputs, but rarely studies present data about material. For agricultural machinery, the specific determination of the energy demand is required, since indices from automobile industry from late 1960s are still adopted. Besides, maintenance is usually based on a percentage of the energy spent on manufacturing. This study evaluates material and energy demand in the maintenance of sugarcane harvesters as: a) suggested by the manufacturer and b) actually done by sugar mills. So, part replacements, labour and material requirements are surveyed. Energy flows are determined by the material demand and material's energy embodiment. According to manufacturer, the maintenance requires 72.8% (2.52 TJ) of the total energy in the life cycle of a sugarcane harvester, while the actual maintenance represents 95.0% (17.93 TJ) of the total energy. The indices change from 158.9 MJ h^{-1} to 869.7 MJ h^{-1} (regarding life time); from 203.2 to 1,112.0 MJ kg^{-1} (regarding mass) and from 13.26 to 72.59 MJ kW^{-1} (regarding power).

KEYWORDS: life cycle assessment; repair; bioenergy; agricultural mechanization

1. Introduction

Energy demand increases as the development of economies and societies happens (Adubakar and Umar, 2006). Humankind has searched alternative sources to fossil energy, mainly using agricultural areas (Macedo *et al.*; 2008). Brazil accounts for around 41% of world's renewable energy, with sugarcane being the second most important source. Sugarcane is responsible for 16.1% of the primary energy in Brazil. Sugarcane provides the raw material for ethanol and bagasse production, responsible for 4.8% and 11.3% of the final energy consumption, respectively (BRASIL, 2014). In Brazil, sugarcane is produced on 8 million ha and mechanical harvesting has increased since 2000 due to economic reasons and environmental constraints (UNICA, 2010).The increasing demand for food, fibre and renewable energy generally demands more energy consumption by production processes (Romanelli and Milan, 2010). To evaluate and monitor production processes, the material flows converging into a product or service ought to be determined (Dyer and Djardins, 2006). The full life cycle of a product regards a set of activities and processes; each one requires a certain amount of material and energy (Manzini and Vezzoli, 2002). Unfortunately, most of the studies present neither data about material flows nor the boundaries of the evaluated system (Romanelli and Milan, 2010). The material flows are the basis for all kinds of environmental evaluation, such as energy flows, which identifies the total energy demand and the efficiency reflected by the net gain and output/input ratio. Besides, in the determination of the energy input all materials and services are taken into account (Romanelli and Milan, 2010).

For agricultural machinery, the determination of the required energy in a product is still considered relatively recent, since most of the indices are based on the automotive production from late 1960s, such as determined by Berry and Fels (1972), 81.2 MJ kg^{-1}.

Usually, energy demand in repair and maintenance is related to the energy required on the machinery production (Doering, 1980; Fluck and Baird, 1980; Mikkola and Ahokas, 2010). The energy demand of repair and maintenance for agricultural machinery varies considerably, with an observed range from 6% to 104%, Table 1 (Fluck, 1985).

For instance, Doering (1980) estimated the embodied energy in agricultural machinery, approaching the energy embodied in the materials and the energy used on assembling phase. He considered the methodology of the total repair accumulated to determine the percentage of required energy in repair and maintenance in the

Original submitted March 2014; revision received August 2014; accepted December 2014.

[1] Engineering of Agricultural Systems, 'Luiz de Queiroz' College of Agriculture, University of Sao Paulo, Brazil.
[2] Corresponding author. Laboratory of Systemic Management and Sustainability. Department of Biosystems Engineering, 'Luiz de Queiroz' College of Agriculture, University of Sao Paulo, Brazil. Av. Pádua Dias, 11 C.P. 9 LEB Piracicaba – SP, Brazil 13418-900. Email: romanelli@usp.br
[3] Laboratory of Systemic Management and Sustainability. Department of Biosystems Engineering, 'Luiz de Queiroz' College of Agriculture, University of Sao Paulo, Brazil.

Table 1: Embodied energy in the repair and maintenance of agricultural machinery

Source (apud Fluck, 1985)	Repair and Maintenance compared to Assembling %	Observations
Pimentel et al. (1973)	6	Corn production, USA.
Bridges and Smith (1979)	6	Following assumptions from Pimentel et al. (1973).
Smill et al., (1983)	8	Based on surveys done with dealers of agricultural machinery.
Foster et al., (1980)	10	Considered only manufacturing of parts
Doering et al. (1977)	32	Based on equations for cost of accumulated repair from ASAE and replacing machinery after 10 years. Energy on assembling excluded the embodied energy on raw material previously to the manufacturing.
Leach (1976)	53	For three power levels of tractors, applying the energy intensity of 200 MJ £$^{-1}$ for repair and maintenance, the average of repair cost was 53% of depreciation.
Burrill et al. (1976)	104	Apple ''Vermont'' production; based in the maintenance cost times the energy intensity of money.

machinery useful life. He assumed 74.25% for AWD (all-wheel drive) tractors and crawlers, 89.10% for tractors 4x2 (rear wheel drive) and 45.88% for trucks, pick-ups, combine, and cotton pickers.

Fluck (1985) presented two models that can be used in the analysis of energy demand called ''industrial cost'' and ''cost of repair in useful life''. To specify energy, the first one considered machinery sales, part replacement and demanded services. The second model considered the energy required for repair and maintenance during the useful life of the machinery, which showed that energy demand in repair and maintenance is 38% higher than the assembling phase and presented a result twice higher than the one obtained by the ''industrial cost'' model.

Some studies determined indices for specific operations, such as Umar (2003) who determined 42.7 MJ ha^{-1} of indirect energy for maintenance, repair and transportation of a tractor-rake combination. This number corresponds to a tractor with mass of 2,780 kg and a useful lifetime of 12,000 h combined with a rake equipment with mass of 564 kg and useful lifetime of 2,000 h, both with operational field capacity of 1.21 ha h^{-1}. Although it is an interesting datum, it would be directly applicable only in similar conditions.

Abubakar and Umar (2006) reported that energy required for maintenance, repair and transportation was not taken into account due to the lack of data of mass of agricultural machinery available in the industries. They concluded that results were not complete, since the neglected activities pose a significant contribution for energy.

This study aimed to compare the material and energy demands in the repair and maintenance suggested by the manufacturers and the one actually performed in sugar mills. As secondary goals, it is intended to determine which are the materials most used in the repair and maintenance and also to assess how close the suggestions made by the manufacturer is to reality in practical field operational conditions.

2. Material and Methods

The repair and maintenance phase considers both either direct inputs (e.g. parts) and indirect inputs (e.g. labour, tools). In this study, the evaluation is performed for two distinct scenarios: the recommendations of the manufacturer and the maintenance observed in a sugar mill.

So, the frequency of part replacement, labour and material requirements was surveyed in the owner's manual (manufacturer's suggestion) or by evaluating records of service orders (sugar mill). For the first scenario, besides the activities suggested in the owner's manual, some activities had to be added because it was not approached by the manual. For instance, the replacement of basal cutting blades replacement is not considered, so this datum was obtained with the post-sale team, dealers and producers. It is important to mention that the replacement of these blades vary due to field conditions (stones), soil texture (sandy, clayey), operators' skills etc. Another datum obtained from the post-sale department of the manufacturer was the life cycle of the evaluated machines, which are used around 3,100 h per year during seven years, resulting in a life cycle of approximately 21,700 h. For the index of embodied energy per time of work, it is necessary to know the life cycle of the sugarcane harvester, which is claimed as uncertain, since it depends upon the level of utilization (Mikkola and Ahokas, 2010).

This study evaluated self-propelled sugarcane harvesters, with 6-cylinder diesel engine power of 260 kW, equipped with metallic tracks, with total weight of 16,972 kg. This kind of harvester represents around 85% of the market share in Brazil. The remaining 15% uses rubber tires instead of metallic tracks.

For the manufacturer's suggestion, it was considered the maintenance schedule of the owner's manual, based on Mantoam *et al*. (2014). For the actual maintenance the services required in the repair shop of a sugar mill was considered. The maintenance of nine harvesters was surveyed during two years either in the harvesting season (April-November) or in the rainy season (December-March), when the industry and machinery are repaired, divided in three groups (three harvesters in each): machines in the first, second and third year of operation. In average, each harvester operated 3,059 h per year. When the survey began, the harvesters presented an average use of 5,260 h.

After the determination of the material flow of all inputs, they were multiplied by the indices of energy embodiment for each input to determine the energy flow. The indices of energy embodiment were obtained from the work of Boustead and Hancock (1979). Therefore, they were used for the input energy flows to be determined. The determination of the embodied energy in indirect inputs, embodied energy in infrastructure depreciation, embodied energy in directly used inputs and embodied energy in repair and maintenance were required in order to sum up the embodied energy in the life cycle of a sugarcane harvester (Eq.1).

The embodied energy in directly used inputs and the embodied energy in repair and maintenance are determined by the quantity of material used and their respective energy indices (Eq. 1).

$$E_{RM} = \sum_{i} I_{RM}(i) \cdot EI_{RM}(i) \qquad (1)$$

Where: EE_{RM} represents the embodied energy in repair and maintenance (MJ), I_{RM} represents the inputs used in the repair and maintenance (kg, L, unit),while EI_{RM} stands for energy index of the inputs used in the repair and maintenance phase (MJ kg $^{-1}$, MJ L $^{-1}$, MJ unit $^{-1}$).

Although the actual situation may indicate the most reasonable option, it should be highlighted that repair and maintenance activities are particular for each sugar mill decision maker or managers. This makes distinct fleets difficult to be compared. Sugarcane harvester is believed to be the machine that is used more in agriculture with around 3,100 h of use within eight months of harvesting. Consequently, it is likely that the share presented by maintenance on energy demand should not be attributed to other machinery. Besides this, sugarcane presents high silicon content in its composition, whose abrasiveness makes sugarcane harvester to last less than harvesters or combines of other crops.

3. Results and Discussion

The material flows in the repair and maintenance in the harvester life cycle, either for the suggested or the actual maintenance by the manufacturer, are presented in Table 2. There is discrepancy on the items listed from both scenarios. Ten of them are listed only in the actual scenario, namely: PLG; solvent; lead; nylon; paint; aluminium; coper; polyethylene; glass; anticorrosive. This can be caused either by unforeseen accidents (glass), or for neglected activities in the manual (PLG used for welding to avoid parts to be rusted, which is very common for this type of harvesters).

Material flows for repair and maintenance are presented in an annual basis and there is discrepancy

Table 2: Material flow used in repair and maintenance phase suggested by manufacturers and done by sugar mills

Items	Unit	Material Flows		Comparison
		Suggested	Actual	Suggested/Actual
		Unit y^{-1}	Unit y^{-1}	
Hydraulic/Lubricant oil	l	1162.5	50,152.1	43.14
Carbon steel	kg	3646.9	9,119.2	2.50
Labour	h	715.2	2,891.6	4.04
Rubber	kg	84.0	1,122.4	13.36
Diesel oil	l	505.2	78.3	0.15
Iron	kg	1602.4	45.3	0.03
Polypropylene	kg	1.7	44.3	26.73
Cellulose film	kg	10.5	5.3	0.51
Grease	kg	222.1	1.7	0.01
Glass fibre	kg	1.4	2.8	1.94
Polyethylene	kg	112.7	-	
Forged steel	kg	-	519.3	
PLG	kg	-	135.7	
Solvent	l	-	111.4	
Lead	kg	-	43.9	
Nylon	kg	-	34.7	
Paint	l	-	33.2	
Aluminium	kg	-	30.2	
Coper	kg	-	22.8	
Polyethylene	kg	-	15.5	
Glass	kg	-	4.8	
Anticorrosive	l	-	2.5	

Table 3: Total energy required for repair and maintenance suggested by the manufacturer and actually performed by the sugar mill

Consumption phase	Suggested		Actual	
	Energy demand		Energy demand	
	GJ	%	GJ	%
Repair and maintenance	2,523.3	72.8	17,928.8	95.0
Parts and components	924.8	26.7	924.8	4.9
LPG, electricity, water	18.8	0.5	18.8	0.1
Infrastructure	0.6	0.0	0.6	0.0
Total	3,467.5	100.0	18,872.9	100.0

Table 4: Energy indexes recalculated for repair and maintenance at the sugar mill

Indicator	Unit	Energy indices	
		Suggested	Actual
Energy per time	MJ h^{-1}	158.9	869.7
Energy per mass	MJ kg^{-1}	203.2	1,112.0
Energy per power	MJ kW^{-1}	13,262.0	72,588.4

again. The highest one is the volume of hydraulic oil that is 43 times higher in the actual scenario. This is caused mainly by poor maintenance, as this type of oil leaks causes unnecessary cost and environmental threats (in soil and watersheds). On the other hand, grease would be expected to be used more than it actually does (just 3%). This may be caused by poor maintenance, which can increase the replacement rate of other items such as steel and iron. Most of the steel is due to the basal cutting blades, which are replaced on every 32 h in average, generating around 1 kg or residues (8 knives).

Further studies should be developed to assess the share of the replaced materials that could be reused or recycled. It is also necessary to verify the distinct kinds of maintenance and the variables that may affect the material demand and consequently, the energy demand and economic cost for sugarcane production.

In order to make the comparison, the annual average of the actual maintenance is extrapolated to the whole life cycle (i.e. seven years). Since the machines are considerably new (5,200 h use out of expected 21,700 h), it is assumed that this would not overestimate the final result (Table 3).

After determining the indicators considering the new value for repair and maintenance, its contribution increased from 72.8% to 95.0% (2,523.3 GJ to 17,928.8 GJ). The total energy consumption increased up to 444.3%, from 3,467.5 to 18,872.9 GJ.

Indicators are calculated considering the embodied energy in time, mass and power of the sugarcane harvesters (Table 4). The increases found considering the automobile industry by Berry and Fels (1972), 81.2 MJ kg^{-1}. The new values should be used to recalculate the efficiency of sugarcane as an energy source.

4. Conclusions

In many cases, the maintenance suggested by manufacturers does not foresee all activities necessary in the actual use. Moreover, variables such as field conditions, decision making, and operator's skill make previsions difficult to be accurate. The results of this work indicate that there is discrepancy between the suggested and actual maintenance performed for sugarcane harvesters.

Further studies should be carried out to deeply monitor distinct kind of maintenance to check their material demand and consequently, economic cost and energy demand. Also, for further research, more detailed study on hydraulic oil is suggested, since it increases cost and may cause environmental hazards in soil and watersheds.

About the authors

Edemilson José Mantoam is a PhD candidate in the Graduate Program of Engineering of Agricultural Systems, with an MSc in Agricultural Machinery from University of Sao Paulo.

Thiago Libório Romanelli is an Associate Professor in the Department of Biosystems Engineering, 'Luiz de Queiroz' College of Agriculture, University of Sao Paulo, Brazil. He received his PhD in Forestry Resources and his MSc in Agricultural Machinery in the same institution.

Marcos Milan is a full Professor on Agricultural Machinery, doing research on Operations Management and Quality Management in agricultural systems. He received his PhD in Agricultural Engineering at the Cranfield University, England.

Acknowledgements

The authors would like to acknowledge FAPESP (Foundation for research support of Sao Paulo state, Brazil) for financing this study (Project 2010/11723-5) and the reviewers who were essential for improving this text.

REFERENCES

Abubakar, M., and Umar, B. (2006). Comparison of energy use patterns in Maiduguri and Yoke flour mills Nigeria. *The CIGR Journal of Scientific Research and Development*, [online] Available at: http://dspace.library.cornell.edu/bitstream/1813/10525/1/EE%2006%20004%20Abubakar%20final%2011Aug2006.pdf. [Accessed 25 July 2013].

Berry, R.S., and Fels, M.F. (1972).*The production and consumption of automobiles*. An energy analysis of the manufacture, discard and reuse of the automobile and its component materials. A report of the Illinois Institute for Environmental Quality. Department of Chemistry, University of Chicago, 74 p.

Boustead, I., and Hancock, G.F. (1979). *Handbook of industrial energy analysis*. London, Ellis Horwood Publishers England, 422 p.

BRASIL (2014). *Brazilian energy balance*. Brasília, 288 p. Available at: https://ben.epe.gov.br/downloads/Relatorio_Final_BEN_2014.pdf. [Acessed 20 July 2014].

Bridges, T.C., and Smith, E.M. (1979). A method for determining the total energy input for agricultural practices. *Transactions of the ASAE*, Michigan, ASAE, 22, 781–784.

Doering, O.C. (1980). Accounting for energy in farm machinery and buildings. In: Pimentel, D. (ed). *Handbook of energy utilization in agriculture*. Boca Raton, Florida: CRC, 9–14.

Dyer, J.A., and Desjardins, R.L. (2006). Carbon dioxide emissions associated with the manufacturing of tractors and farm machinery in Canada. *Biosystems Engineering*, 93 (1), 107–118. DOI: 10.1016/j.biosystemseng.2005.09.011.

Fluck, R.C., and Baird, C.D. (1980). Agricultural energetics. AVI Publishers Co Westport, 192 p.

Fluck, R.C. (1985). Energy sequestered in repairs and maintenance of agricultural machinery. *Transactions of the ASAE.* Michigan, ASAE, 28, 738–744.

Macedo, I.C., Seabra, J.E.A., and Silva, J.E.A.R. (2008). Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020. *Biomass and Bioenergy*, 32, 582–595. DOI: 10.1016/j.biombioe.2007.12.006.

Mantoam, E.J., Milan, M., Gimenez, L.M., and Romanelli, T.L. (2014) Embodied energy of sugarcane harvesters. *Biosystems Engineering*. 118(1), 156–166. DOI: 10.1016/j.biosystemseng.2013.12.003.

Manzini, E., and Vezzoli, C. (2002).*Development of sustainable products* (in portuguese). São Paulo, Editora da Universidade de São Paulo, 368 p.

Mikkola, H.J., and Ahokas, J. (2010). Indirect energy input of agricultural machinery in bioenergy production. *Renewable Energy*, 35, 23–28. DOI: 10.1016/j.renene.2009.05.010

Romanelll, T.L., and Milan, M. (2010). Material flow determination trough agricultural machinery management. *Scientia Agricola*. 67(4), 375–383. DOI: 10.1590/S0103-90162010000400001.

Umar, B. (2003). Comparison of manual and manual-cum-mechanical energy uses in groundnut production in a semi-arid environment. *The CIGR Journal of Scientific Research and Development*. [online] Available at http://ecommons.library.cornell.edu/bitstream/1813/10318/1/EE%2003%20003%20Umar.pdf. [Accessed 27 August 2014].

UNICA (2010). *Agricultural and environmental protocol of sugarcane sector* (in portuguese). Available at: http://www.unica.com.br. [Accessed in: 28 July 2014].

