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A financial and environmental evaluation for the introduction of diesel-hydraulic hybrid-drive system in urban waste collection

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ABSTRACT

This paper discusses the efficiency and feasibility of diesel-hydraulic hybrid-drive technology applied to urban waste collection trucks, regarding a financial and environmental focus. The analysis is based on uniform monthly costs cash flow of the diesel-hydraulic hybrid-drive system implementation, considering its elements, such as equipment and maintenance cost, and also taking under consideration the range of efficiency identified on the literature review and endorsed data collect in a field test. It was found that for the efficiencies of 15% and 25%, the implementation of the suggested technology are favorable for waste collection trucks with 2 and 3 axes, from 6 to 19 m^3 capacity, which are found in the Municipal Urban Cleaning Company (COMLURB) fleet of 223 vehicles. Better figures leads to 120,190 l of diesel saved each month what means US$ 123,796.29 and 330.66 t of CO_2. If high carbon benefit price of U$ 5500/t is introduced the improvement in monetary economy reaches 14.26% (US$ 17,656.60). These benefits are better distributed by vehicle type than by fleet size and 80.56% of then are related to the fleet of 15–19 m^3 capacity waste collection as far as they represent 79.37% of the entire fleet.

Introduction

The increasing competition in the global market and the development of environmental protection laws boosted the needs of the automobile industry to introduce significant improvements in fuel economy for all vehicle classes.

Meanwhile, the fuel consumption's rate per truck increased more than per passenger vehicles (Huo et al., 2012). This is a consequence of an increase in the number of light trucks, as well as increased demand for freight transport. It is becoming usual the use of new technologies in trucks that increases the capability to reduce fuel consumption through the use of highly efficient diesel engines and propulsion systems (McKinnon et al., 2010).

In the year of 2010, the Brazilian transport sector consumed 53.1% of petroleum derivatives, of which 90% was used in road transportation (Souza et al., 2012). Considering also that road transport is the main transport mode in Brazil, leading to a significant fuel consumption cost.

The use of diesel-hydraulic hybrid-drive technology is not as common as diesel-electric hybrid-drive. However the diesel-electric hybrid-drive is more expensive mainly because of the use of batteries. Therefore, this paper brings an innovative

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research proposal. Firstly, because it intends to evaluate the financial and environmental benefits of diesel-hydraulic hybrid-drive technology applied to heavy-duty vehicles propulsion system. The second reason is the applicability test of this technology on trucks used for urban waste collection where the street operation cycle has many stop-and-go cycles. Furthermore, through a research on the "Science Direct" website, with the key words "hydraulic hybrid-drive" and "diesel-hydraulic hybrid-drive", it was not found, at least, in the past 5 years any article that proposes a feasibility analysis for the implementation of this technology in any kind of vehicle. The articles found on diesel-hydraulic hybrid-drive focus on its mechanical design improvement and energy balance on the vehicle (Hui et al., 2009, 2011; Hui and Junqing, 2010; Hui, 2010).

As main objective this article proposes a financial and environmental evaluation of the diesel-hydraulic hybrid-drive technology applied to urban waste collection truck's fleet of the Municipal Urban Cleaning Company (COMLURB), on Rio de Janeiro. It also describes the field test procedure and tried technology.

After this introduction, 'Diesel-hydraulic hybrid-drive technology review' presents the concept and a brief review of diesel-hydraulic hybrid-drive technology in order to establish its potential to improve fuel economy in heavy-duty vehicles street operation. 'The tested diesel-hydraulic hybrid-drive technology description' shows a description of the tried diesel-hydraulic hybrid-drive technology. The field test procedure, the statistical method and the financial and environmental evaluation methodology are described and the data is presented in 'Methodology and data'. 'Results and discussion' deals with results and its discussion and 'Conclusions' brings the conclusions.

Diesel-hydraulic hybrid-drive technology review

A diesel-hydraulic hybrid-drive system use hydro pneumatic accumulators to capture and store kinetic energy that would be dissipated during braking of the mechanical-drive vehicle and return energy to drivetrain during vehicle acceleration. The recovery of braking energy is particularly interesting for vehicles that operate in stop-and-go cycles (Baseley et al., 2007).

Studies related to hybrid-hydraulic hybrid-drive technology initiated on 1970's decade, USA and Germany were pioneers in developing this kind of technology (Rodrigues, 2010), tested mainly on buses and waste collection trucks. From 1980 to 2010 it was registered tests of diesel-hydraulic hybrid-drive technology in a variety of vehicles, as presented on Table 1.

The Fig. 1 represents the energy distribution that reaches the wheels of a 9t TGW vehicle during an urban and highway cycle operation. About 40% of the total energy that reaches the wheels is dissipated during braking on urban operation. For the same vehicle, however with operational cycle out of town (in highways, for example), the energy dissipated during braking is only 9% of the total energy that is transferred to the wheels.

Comparing the two graphs of Fig. 1 shows that the urban cycle operation, frequently stop-and-go cycles, favors the use of diesel-hydraulic hybrid-drive technology, recovering some of the kinetic energy that would be wasted in braking.

Only over the last few years diesel-hydraulic hybrid-drive reemerged as viable technology, especially in applications to medium and larger commercial vehicles due to environmental protection pressure and its relatively small price and maintenance benefits if compared to other options, like diesel-electric hybrid-drive systems.

A diesel-hydraulic hybrid-drive system would have a lifetime of 10 or more years and extend the lifetime of other parts on the vehicle, where a diesel-electric hybrid-drive system would only have a lifetime of 5 years and the lifetime of an ultra-capacitor diesel-electric hybrid system is unknown (Lindzus and Conrad, 2008).

In today's diesel-electric hybrid-drive systems for heavy commercial vehicles the batteries must be replaced after 3–4 years, which calls for extra work and extra costs. This replacement is not needed with a diesel-hydraulic hybrid-drive system. All main components are designed to the lifespan of the vehicle. The hydraulic components require only minor maintenance effort, which can be handled easily by an experienced truck workshop, mainly in the case the mechanics are

Table 1
Potential improvement in fuel economy.

Manufacturer	Model	Type	Improvement in fuel economy	
			Minimum (%)	Maximum (%)
MAN	Hydrobus	Parallel	21	28
Ford	Light-duty Truck (F 550)	Parallel	20	30
Ford	Microbus (E 450)	Parallel	–	25
NI	Heavy-duty waste collection truck[a]	Parallel	15	25
Mercedes Benz	Heavy-duty waste collection truck (Actros)[b]	Parallel	–	25
Volvo	Bus[c]	Series	30	35
NI	Light-duty truck[d]	Series	45	50
NAC	Medium-duty truck[e]	Series	25	35

NI – not informed. *Source:* adapted from Rodrigues (2010).
[a] Manufacturer not informed, but used diesel-hydraulic hybrid-drive system of Bosch Rexroth, with 20t TGW and maximum power of 280 hp.
[b] Vehicle of 26t TGW and maximum power of 320 hp.
[c] Model, TGW and maximum power not informed.
[d] Manufacture, model, TGW and maximum power not informed.
[e] Model, TGW and maximum power not informed.