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Global energy consumption due to friction in trucks and buses

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ABSTRACT

In this paper, we report the global fuel energy consumption in heavy-duty road vehicles due to friction in engines, transmissions, tires, auxiliary equipment, and brakes. Four categories of vehicle, representing an average of the global fleet of heavy vehicles, were studied: single-unit trucks, truck and trailer combinations, city buses, and coaches. Friction losses in tribocontacts were estimated by drawing upon the literature on prevailing contact mechanics and lubrication mechanisms. Coefficients of friction in the tribocontacts were estimated based on available information in the literature for four cases: (1) the average vehicle in use today, (2) a vehicle with today's best commercial tribological technology, (3) a vehicle with today's most advanced technology based upon recent research and development, and (4) a vehicle with the best futuristic technology forecasted in the next 12 years. The following conclusions were reached:

- In heavy duty vehicles, 33% of the fuel energy is used to overcome friction in the engine, transmission, tires, auxiliary equipment, and brakes. The parasitic frictional losses, with braking friction excluded, are 26% of the fuel energy. In total, 34% of the fuel energy is used to move the vehicle.
- Worldwide, 180,000 million liters of fuel was used in 2012 to overcome friction in heavy duty vehicles. This equals 6.5 million TJ/a; hence, reduction in frictional losses can provide significant benefits in fuel economy. A reduction in friction results in a 2.5 times improvement in fuel economy, as exhaust and cooling losses are reduced as well.
- Globally a single-unit truck uses on average 1500 l of diesel fuel per year to overcome friction losses; a truck and trailer combination, 12,500 l; a city bus, 12,700 l; and a coach, 7100 l.
- By taking advantage of new technology for friction reduction in heavy duty vehicles, friction losses could be reduced by 14% in the short term (4 to 8 years) and by 37% in the long term (8 to 12 years). In the short term, this would annually equal worldwide savings of 105,000 million euros, 75,000 million liters of diesel fuel, and a CO_2 emission reduction of 200 million tones. In the long term, the annual benefit would be 280,000 million euros, 200,000 million liters of fuel, and a CO_2 emission reduction of 530 million tonnes.
- Hybridization and electrification are expected to penetrate only certain niches of the heavy-duty vehicle sector. In the case of city buses and delivery trucks, hybridization can cut fuel consumption by 25% to 30%, but there is little to gain in the case of coaches and long-haul trucks. Downsizing the internal combustion engine and using recuperative braking energy can also reduce friction losses.
- Electrification is best suited for city buses and delivery trucks. The energy used to overcome friction in electric vehicles is estimated to be less than half of that of conventional diesel vehicles.

Potential new remedies to reduce friction in heavy duty vehicles include the use of advanced low-friction coatings and surface texturing technology on sliding, rolling, and reciprocating engine and transmission components, new low-viscosity and low-shear lubricants and additives, and new tire designs that reduce rolling friction.

1. Introduction

During the past two decades, global awareness of the need for more fuel-efficient and environmentally benign transportation systems has increased tremendously, mainly because of limited petroleum reserves, skyrocketing fuel prices, and much tougher

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environmental regulations to combat greenhouse gas emissions. Accordingly, researchers have been exploring new strategies to improve fuel economy and environmental compatibility of future transportation systems. While alternative ways to power future transportation systems with low-carbon energy resources, including biofuels, natural gas, electricity, etc., are under development, more advanced materials and lubrication technologies are also being explored to cut down parasitic energy losses due to friction in the moving parts of modern engines [1,2].

In a recent comprehensive study focused on passenger cars, Holmberg et al. [3] determined that nearly one-third of the fuel's energy is spent to overcome friction in passenger cars. The same study advocated that, with the adaptation of more advanced friction control technologies, parasitic energy losses due to friction in engines could be reduced by 18% within the next 5 to 10 years, which would result in global fuel savings of 117,000 million liters annually, and by 61% within the next 15 to 25 years, which would result in fuel savings of 385,000 million liters annually. These figures equal world-wide economic savings of 174,000 million euros in the next 5 to 10 years and 576,000 million euros in the next 15 to 25 years. Such a fuel efficiency improvement in passenger cars would, furthermore, reduce CO_2 emission by 290 million and 960 million tons per year, respectively. The estimation of the global saving potential is in agreement with detailed energy calculations carried out for passenger cars in Japan by Nakamura [4]. This level of savings should have a significant positive impact on the global efforts to reduce the greenhouse effect and control global warming.

Most passenger cars are privately owned and not used for commercial services. While cars are important to individual transportation, commercial heavy duty vehicles, such as buses and trucks, are critical to society at large because they are used for mass transportation of people, products, and services. Indeed, buses are the backbone of most public transportation systems in the world. Interestingly, only 12% of world freight is carried on some form of road vehicle, while 13% is by rail, 75% by ships, and 0.3% by aviation [5,6]. However, the picture looks very different in terms of total transport energy consumption, for which 73% is consumed by road transport, 3% by rail, 10% by ships, and 10% by aviation [7], as shown in Fig. 1. Heavy duty vehicles represent 36% of the road transport oil consumption [8].

In terms of energy consumption, ranking second is heavy duty vehicles, comprising both trucks and buses (21%). Therefore, the energy consumption of this segment deserves close attention for the following reasons:

- Despite the relatively low numbers of such vehicles, their share of the energy use is high.

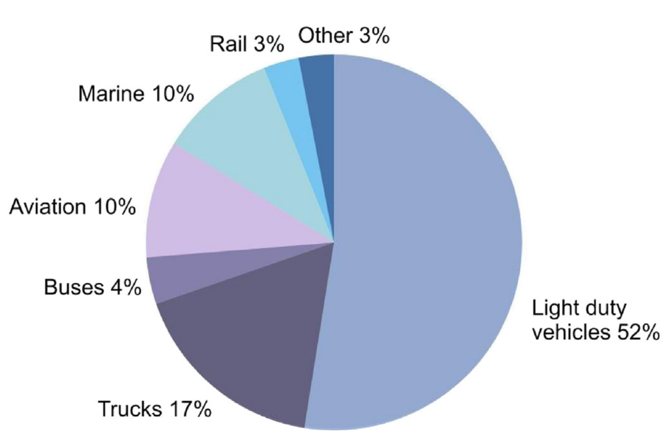

Fig. 1. Global breakdown of the energy consumption by transportation vehicles [7]. The 52% share by the light duty vehicles includes 37% passenger cars and 15% vans, pick-ups, and sport utility vehicles.

- They have strategic importance to society (see above).
- They rely heavily on diesel fuel, and internal combustion engines will still be used for a long period of time, especially in the case of long-haul heavy duty trucks, since the electrification of trucks is more challenging than that of light duty vehicles.
- Their driving range and load profiles differ significantly from those of passenger cars.
- Commercial heavy duty vehicles are often part of fleets: it is thus easier to influence decision-making concerning these vehicles compared to passenger cars.
- The fuel economy ratings and carbon footprint of heavy duty vehicles are rather dismal and need urgent improvement.

For heavy duty vehicles, the power-to-weight ratio, and thus the average relative load, is quite different compared to passenger cars. In the case of passenger cars, significant fuel savings can be achieved by downsizing and choosing less powerful vehicles. Commercial vehicles are, in most cases, more tailored for their purpose than passenger cars; hence, the potential for fuel savings by downsizing is not as obvious as in the case of passenger cars [9,10].

Buses, and especially city buses, constitute a relatively homogeneous vehicle category in terms of energy consumption. For a city bus, operated on low average speed, with a frequent stop-and-go pattern, a major portion of the fuel energy is used for accelerating the vehicle. Consequently, without hybridization, a large amount of energy is lost when decelerating the vehicle by using the brakes. Coaches, by contrast, are operated at much higher and constant cruising speeds, at which aerodynamic drag becomes far more important than the weight and rolling resistance.

For trucks used for goods transporting, the gross weight and configuration of the vehicle vary significantly. The gross vehicle weight range is from some 3.5 t up to 60 t or even more. Duty cycles vary from start-and-stop type driving typical of urban settings to the constant high-speed cruising of long-haul trucks.

Our earlier paper reviewed the global energy consumption due to friction in passenger cars [3]. This review presents calculations of the global energy consumption due to friction and potential savings through the adaption of advanced friction control technologies in trucks and buses. We focus on four categories of heavy duty vehicles: single-unit trucks, truck and trailer combinations, city buses, and coaches. The vehicles were chosen to represent an average of the world heavy vehicle fleet. We base our calculations on vehicles with diesel engines. We discuss the effect of future change to electrical motors separately. Other expected changes, such as improvements in aerodynamics and a more extensive use of light-weight materials, and related predictions, are not included in the present analysis.

2. Methodology

The present analysis is carried out according to a methodology developed by Holmberg et al. [3,11]. It is based on the combination of analyses on several physical phenomena resulting in the energy consumption in vehicles. The methodology includes five parts:

1. The global energy consumption of heavy duty vehicles.
2. The distribution of the friction and energy losses in four categories of heavy duty vehicle (single-unit truck, truck and trailer combination, city bus, and coach).
3. Driving cycle effects in the four vehicle categories.
4. Tribocontact friction levels today and in the future.
5. The global fuel consumption today due to frictional losses and potential savings.

The calculations of friction energy loss proceed in the following way: (1) The global fleet of heavy duty vehicles is estimated. (2) Its