Global Impact of Friction on Energy Consumption, Economy and Environment

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Worldwide about 100 million terajoule is used annually to overcome friction and that is one fifth of all energy produced. The largest quantities of energy are used by industry (29 %) and in transportation (27 %). Based on our recent studies on energy use in passenger cars, trucks and buses, we concluded that it is possible to save as much as 17.5 % of the energy use in road transports in the short term (5 – 9 years) by effective implementation of new tribological solutions. This equals to annual energy savings of 11.6 exajoules, fuel savings of 330 billion litres and reduction in CO_2 emission by 860 million tonnes. In a paper mill, 15 – 25 % of the energy used is spent to overcome friction. The electrical energy used by a paper machine is distributed as 32 % to overcome friction, 36 % for the paper production and mass transportation, and 32 % is other losses. In paper machines, 11 % of the total energy used to overcome friction can be saved by the implementation of new tribological technologies. An overview of the total energy saving potential globally by improved tribological solutions is presented.

Keywords: *friction, energy, lubrication, transportation.*

1. INTRODUCTION

Energy is a key resource for our society today and will be crucial for our sustainability in the future. A considerable amount of energy is consumed to overcome friction, especially in the transportation, industrial, and power-generation sectors, and major economic losses are also due to wear of products and components and their replacement. Jost [1] concluded that studies carried out in several industrial countries indicate that 1.0 to 1.4 % of the gross national product can be saved by introducing better tribological practices, requiring investment in research and development at a rate of one in 50 of the savings obtainable.

Today, considerable effort is being devoted to producing increasingly more energy efficient vehicles and machines, not only for economic reasons, but also to help meet the requirements for reduced CO_2 emissions arising from the Kyoto Protocol on climate change. A major source of CO_2 emissions are cars and trucks. Transportation consumes about 20 % of the global primary energy and accounts for about 18 % of the total anthropogenic greenhouse gas emissions [2,3].

In this paper we summarize our studies for calculating the global energy consumption due to friction and potential savings from friction reduction in transportation and in industry [4-6]. We first focused our attention on passenger cars for two reasons: passenger cars form a major consumer of energy and also generate a considerable part of the greenhouse gas emissions. The other reason was that the energy use in passenger cars has been largely studied on the system-to-component level. The present study is based on the current set of technical solutions for passenger cars, trucks, buses and advanced industrial processing machinery here represented by paper machines, while the effects of expected changes, future trends, and predictions in this set are not included.

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2. GLOBAL ENERGY CONSUMPTION AND ENVIRONMENTAL ASPECTS

The energy production worldwide (Total Primary Energy Supply TPES) was 13113 million tonnes oil equivalent (Mtoe) in 2011 which equals to 549 EJ [7]. Of this, about one third was consumed within the energy sector by power plants, furnaces, energy transfer losses and energy industry's own use leaving 373 EJ for the global final energy consumption (Total Final Consumption TFC). This part was used by industry (29 %), transportation (27 %) and other energy consumers like households and services (35 %) and for non-energy use (9 %) such as for raw materials. Oil is the largest part of the global energy supply (41 %) by a value of 152 EJ, as shown in Figure 1. Oil is also the main source of energy for the transportation sector covering 96 % of its energy need.

The global emission of CO_2, the major greenhouse gas, is steadily increasing since the beginning of industrial revolution and reached a level of 31,600 Mt in year 2011 [8]. The world transportation generated 23 % of this (7200 Mt) and the largest part came from road transport. In the year 2009, 71.7 % of all transportation CO_2 emissions in Europe came from road transport, 14.6 % from marine, 12.3 % from aviation and 0.8 % from rail transport [9].

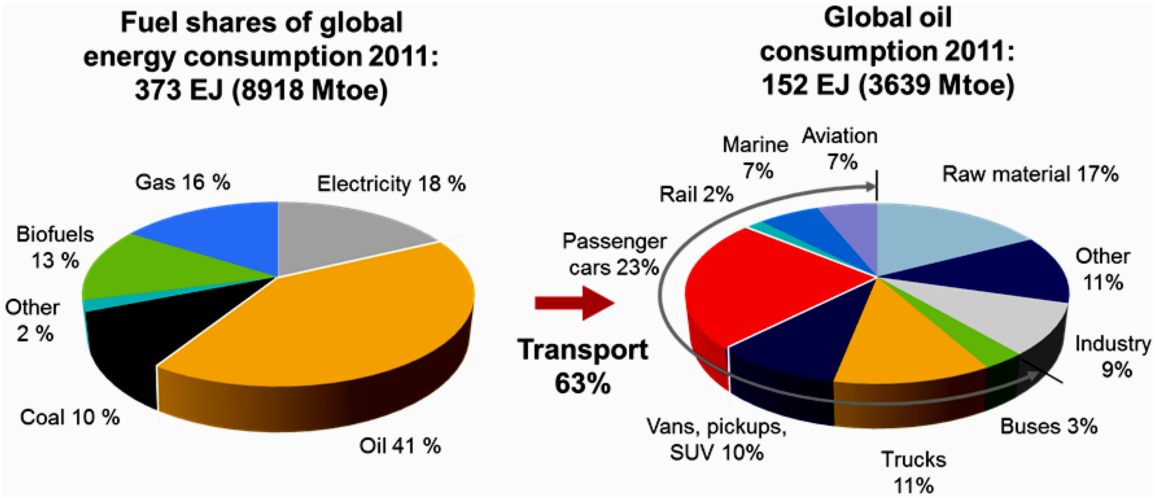

Figure 1. Global energy and oil consumption 2011 [7]

3. ENERGY CONSUMPTION IN TRANSPORTATION

Transportation accounts for 63 % of the total global oil consumption. The rest is used by industry, for raw materials and other uses. Within the transportation sector, road traffic is the largest user of energy (73 %) followed by marine (10 %), aviation (10 %) and rail (3 %) traffic [10]. However, the ships are the largest carrier of world freight (75 %) followed by rail (13 %), road vehicles (12 %) and aviation (0.3 %) [11-13].

On average, 21 GJ is annually used by road vehicles to overcome friction [4,6]. We have estimated based on statistics on general level that an average air craft would use about 2800 GJ annually to overcome friction, a train 8300 GJ and a marine vessel 30,000 GJ.

4. ENERGY CONSUMPTION IN ROAD TRAFFIC

The road traffic is dominated by 700 million passenger cars and 300 million other light vehicles like vans, pick-ups and sport utility vehicles (SUV) in terms of number of vehicles. In addition, there are 36.5 million single-unit trucks, with a total weight over 3.5 tonnes, and truck and trailer combinations, and 3.6 million city buses and coaches.

The passenger cars use 11.2 EJ annually and the vans, pickups and SUVs use 4.6 EJ annually to overcome friction. The corresponding numbers for trucks and truck and trailer combinations is 4.9 EJ and for buses and coaches 1.3 EJ. The annual energy use per vehicle unit is highest for city buses, truck and trailer combinations and coaches.

Breakdown of the energy use in an average passenger car on global level is shown in Figure 2. More than half of the fuel energy in an internal combustion engine goes to exhaust (33 %) and cooling (29 %), while the rest is transformed to mechanical power (38 %). Of this part are the total frictional losses the main part (33 %), while the air drag (5 %) is a minor part. The largest groups of parasitic friction losses are those in the engine (11.5 %), in the transmission system (5 %) and that for overcoming rolling friction of the tires (11.5 %). In addition, mechanical power is consumed by friction losses when braking and this deceleration energy can be on average considered as equal to the energy used for accelerating the vehicle. Thus actually only 21.5 % of the fuel energy is used for moving the car, consisting of the tire rolling resistance, the air drag and the brake/acceleration energy, while the rest are energy losses.

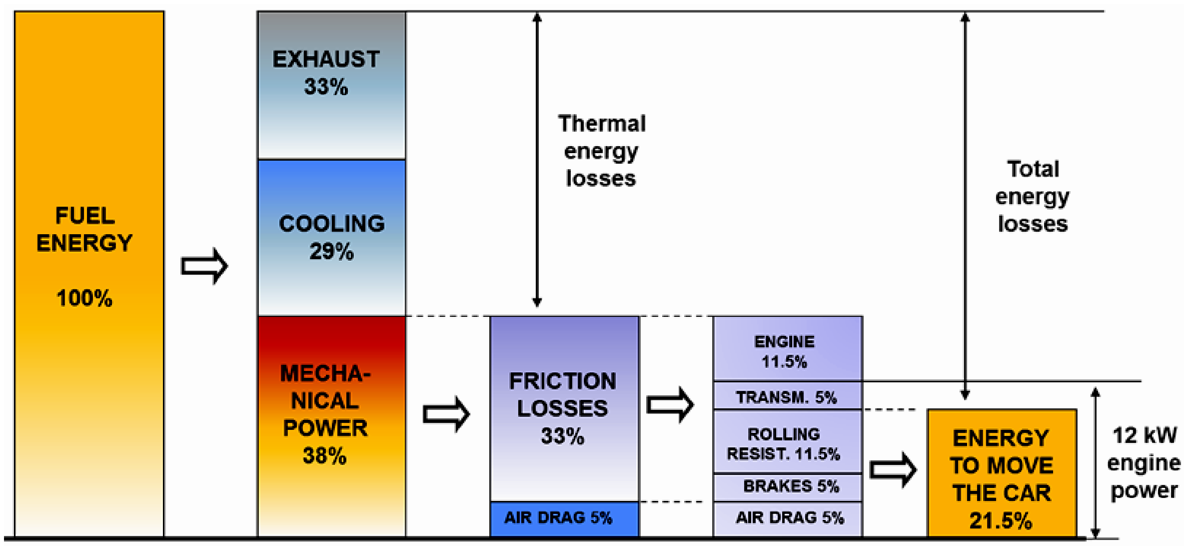

Figure 2. Breakdown of passenger car fuel energy consumption [4]

The frictional losses are 33 % of the total fuel energy and of this is 35 % consumed in the tire-road rolling contacts, 17 % in elastohydrodynamic contacts, 16 % in hydrodynamic contacts, 8 % in mixed and 2 % in boundary lubricated contacts. Viscous losses are 7 % and braking takes 15 % [4].

5. POTENTIAL SAVINGS IN ROAD TRANSPORTATION

Friction is a major energy consumer in transportation representing some 25 to 30 % of the total energy use. However, new tribological knowledge and developments have resulted in breakthrough solutions where the friction has been reduced by even 50 to 90 % from the level normally found in vehicles in use today [4,6]. Figure 3 shows this trend as estimated for the different tribological contact and friction mechanisms in heavy duty vehicles. The technology behind has been presented by Holmberg et al. [4,6].

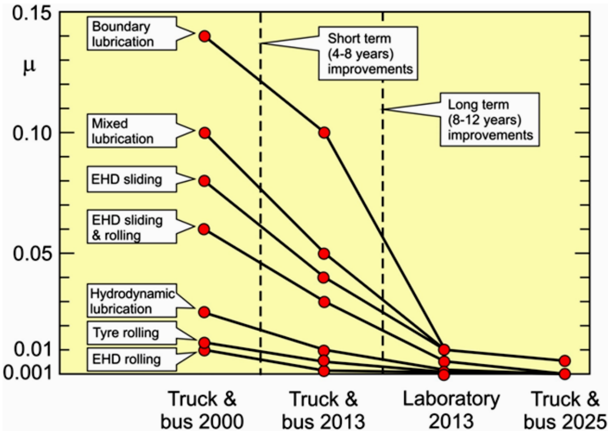

Figure 3. Trends in coefficient of friction reduction in four truck and bus categories for different lubrication mechanisms and for rolling friction

Holmberg et al. [6] calculated for heavy duty vehicles that by implementing the most advanced tribological solutions in use in modern commercial heavy vehicles of today in all vehicles world-wide, the energy consumption due to friction could be reduced by 37 % (Truck & bus 2013; in Fig. 3). If the best tribological solutions demonstrated in research laboratories were in use, this factor would be reduced by 60 % (Laboratory 2013), and if the new solutions forecasted for 2025 were in use, it would be 68 % (Truck & bus 2025). Obviously, implementing today's advanced commercial solutions in all trucks and buses would require an enormous effort and would result in large implementation costs, which cannot be commercially justified. Nonetheless, it would be realistic to estimate that perhaps half of this level could be reached in the short term, within four to eight years, by large scale concentrated research, development and implementation efforts on new tribological solutions resulting in 14 % reduction in fuel consumption, as shown in Figure 3. The realistic long term reduction in fuel consumption was calculated to be 37 %.

Due to the smaller number of heavy duty vehicles in the global fleet, the smaller number of vehicle owners, and their better organization, compared to owners of passenger cars, it has been assumed that changes to lower friction losses are easier to implement and will thus have a more rapid effect. It was estimated that a short-term penetration time for the global fleet of heavy duty vehicles is 4 – 8 years, compared with the 5 – 10 years for passenger cars.

6. ENERGY CONSUMPTION IN PAPER MACHINES

In another study, we calculated the energy need to overcome friction in an advanced industrial production machine as represented by a paper machine [5]. There were 8525 paper machines in operation worldwide and they used 101,400 GWh of electrical power in 2012 to overcome friction. In this study, we used the same methodology as above for cars and defined the global average paper machine and its global average operating conditions. This machine was analysed in detail.

The electrical energy consumed forms no more than 30 % of the total paper machine energy consumption. The remaining part is 67 % steam energy for process heating and 3 % factory fuels.

The direct friction losses are 9.2 % of the total paper machine energy consumption and 32 % of the electrical energy used. Of this 48 % was consumed in EHD contacts, 9 % in HD contacts, 18 % in seal boundary lubricated seal contacts, 23 % in water lubricated sliding contacts at fabrics and 2 % in water lubricated sliding contacts at doctor blades. The breakdown of energy consumption in the global average paper machine is shown in Figure 4.

We estimated that by taking advantage of new technology for friction reduction in paper machines, friction losses could be reduced by 11 % in the short term (about 10 years), and by 23.6 % in the long term (20 – 25 years). This would equal to worldwide economic savings of 2000 million Euros, electricity savings of 36,000 GWh, and CO_2 emission reductions of 10.6 million tonnes in the short term and economic savings of 4200 million Euros, electricity savings of 78,000 GWh, and CO_2 emission reductions of 22.7 million tonnes in the long term.

Potential mechanisms to reduce friction in paper machines include the use of low-friction and highly durable coatings, surface engineering including texturing, low-viscosity and low-shear lubricants and fluids, novel additives, new materials in seals, doctor blades and fabrics, as well as new designs.

7. ENERGY CONSUMPTION IN MINING

In an ongoing investigation, we analyse the energy use to overcome friction and the economic effects of wear in the mining industry. While paper industry represents a highly automated and advanced industrial field the mining sector is technologically much less advanced on global scale and tribologically the interactions in moving contacts, especially in mineral breaking and crunching, are extremely severe.

In an electrically powered grinding machine of average size, only 10 % of the energy is used for crushing the minerals and almost half of the energy is used to overcome friction, as shown in Figure 5.

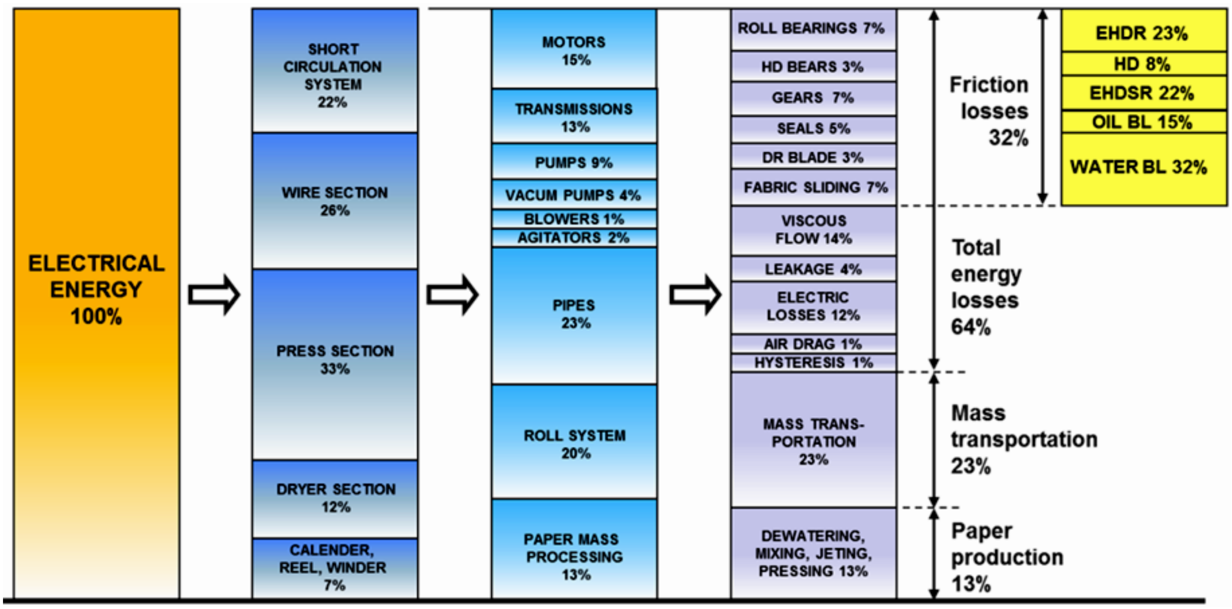

Figure 4. Breakdown of the global average paper machine energy consumption [5]

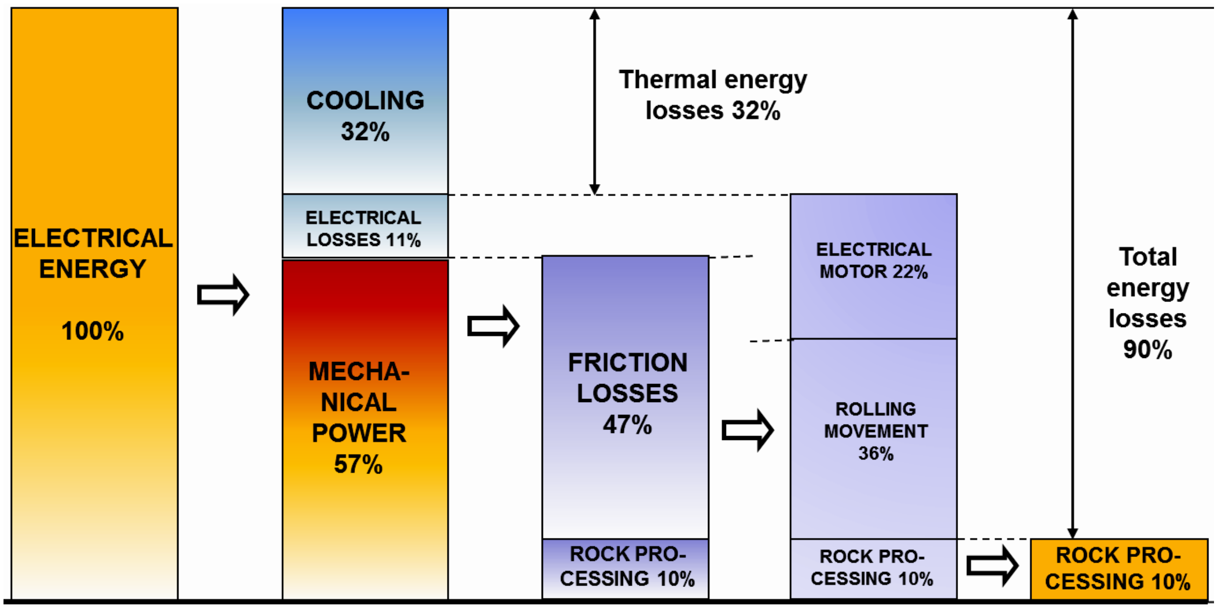

Figure 5. Breakdown of the global average energy consumption of an electrically powered grinding machinery in mining

Wear has a major influence in the mining processes and for that reason we will include also calculations on the economic, energy and environmental impact of wear in this study. Our first calculations seem to indicate that in mining the impact of wear is economically of the same order of magnitude as that of friction.

8. CONCLUSIONS

Based on the very detailed analysis of three cases – passenger cars, trucks and buses representing the transportation sector and paper machines representing the industrial sector – this study gives us some insights into how much energy is lost to overcome friction and how to control it to improve the efficiency of future mechanical systems.

Transport and industry are the two largest users of energy, and they are currently consuming almost one third each of the total energy production. About 30 % of the energy in transport is used to overcome friction, while in industry the corresponding amount is about 15 – 20 %. In residential and other areas, the energy used to overcome friction is less than 10 %. The overall conclusion is that about 20 % of the total energy production in the world is used to overcome friction.

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ГЛОБАЛНИ УТИЦАЈ ТРЕЊА НА ПОТРОШЊУ ЕНЕРГИЈЕ, ЕКОНОМИЈУ И ЖИВОТНУ СРЕДИНУ

Кенет Холмберг, Али Ердемир

У свету се годишње троши око 100 милиона тераџула енергије да би се савладало трење, што чини једну петину од укупно произведене енергије. Највећа потрошња укупно произведене енергије је у индустрији (29 %) и транспорту (27 %). Аутори су, на основу својих скорашњих истраживања о потрошњи енергије у путничким аутомобилима, камионима и аутобусима, дошли до закључка да је могуће да се оствари и до 17,5 % уштеде енергије која се користи у друмском саобраћају у релативно кратком временском року (5 до 9 година) применом нових триболошких решења. Ово би на годишњем нивоу довело до уштеде енергије од 11,6 ексаџула, уштеде горива од 330 милијарди литара и смањењу емисије CO_2 од 860 милиона тона. У фабрици папира се 15 – 25 % енергије утроши на савладавање трења. Расподела електричне енергије коју користи машина за производњу папира је следећа: 32 % се утроши на савладавање трења, 36 % се утроши на производњу папира, а 32 % су остали губици. У овим машинама је могућа уштеда од 11 % од укупне енергије која се троши на свладавање трења применом нових триболошких решења. У раду је дат преглед могућности уштеде укупно произведене енергије на светском нивоу, применом одговарајућих триболошких побољшања.