

Tribology as Energy Saver

A Case Study of Indian Road Transport Industry

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Of late importance of limiting the use of energy from fossil source have been felt because of the environmental protection & conditional availability globally. Crude oil has been the main source of primary energy supply globally & it contributes 25% of India’s primary energy supply and is the second largest after coal, which contributed 44% of the primary energy supply (IEA, 2021). Currently, India is the world’s 3rd largest consumer of oil, 3rd largest LPG consumer, 4th largest LNG importer, 4th largest refiner and 4th largest automobile market. The ultimate thermal energy efficiency is observed as ~1/3rd only. Wear and friction issues are very detrimental as it reduces the machine’s efficiency. Dr Jost proposed the potential savings of 515 million UK pounds (1.36% of UK’s GNP) in this area through tribology in 1966. We knew from the textbooks of 25 years ago, that the lowest coefficient of friction between two sliding solid surfaces through PTFE (polytetrafluoroethylene) contacts was ~0.08. But with the technology advancement today, it has gone down to the far lower i.e. 0.0005 levels. By applying a thin layer of only a few micrometres (called microns) does not change the component geometry much but improves its both friction and wear (Holmberg & Matthews 2009).

Status on energy usage in—Road Transportation Industry in India

The maximum consumption of energy in transport is i.e. 76% through road transport among railways, aviation, navigation & pipeline etc. in 2023-24 (Fig-1a). High speed diesel (38%) accounted for the largest share of growth in the petroleum products followed by petrol (16%), LPG (13%) and others (Fig-1b) as per BEE India Energy Scenario Report-2024. Thus, efficient use of the fuel oil is of paramount priority.

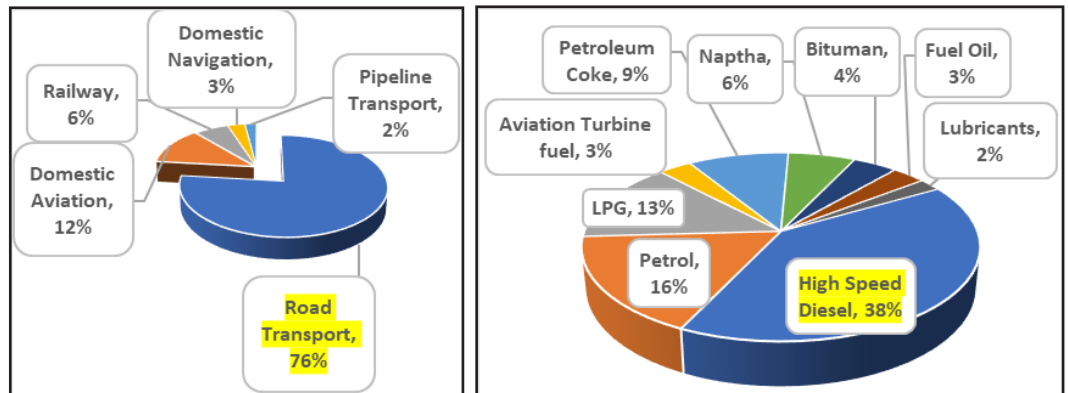


Fig-1a: Sector wise Energy Consumption in Transport in India (2023-24E)

Fig-1b: Consumption of Petroleum products in India (2023-24E)

Frictions and wear status on energy usage, in internal combustion engine (ICE) passengers—Car, Jeep, SUV

As per VAHAN data (MORT&H) of 2022, there are ~ 50 million cars, jeeps, SUVs, taxis in India (world’s 1/28th). Inside the ICE the fuel is broken down from liquid hydrocarbons having chemical structure & burnt which releases the gas pressure (Fig-2). Partly it moves the piston to give power to run the car by overcoming both air drag and frictional losses & part of it goes into exhaust gases, mainly CO₂, H₂O, and NO_x. In a typical passenger car, only 20% of the fuel is used to

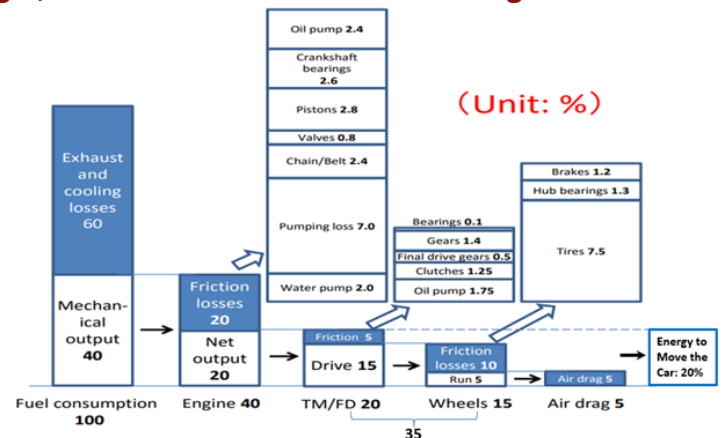


Fig-2: Distribution of energy in ICE driven passenger cars, tank-to-wheel calculations

move the car, and the remaining 80% accounts for the energy losses. To move a car, about 60% energy goes for its cooling & exhaust, 35% is converted to overcome friction loss & 5% to overcome air drag (Fig-2) (Takashi Nakamura, 2017).

Methods for reduction of friction losses in cars of 2020

a) For engine oil pumps—Low viscosity Oil (LVO), b) for main & big end bearings of crankshaft—narrow bearing, texture, surface treatment with low friction coatings, c) for piston & its rings-narrow piston skirt, low ring tension, surface treatment, d) for pumping loss—exhaust gas recirculation, Miller cycle, e) for water pump-seal improvement, electric drive, f) for transmission bearings—downsize, LVO, ball bearing, g) for final drive & gearbox-gears of high accuracy, LVO, h) for wheels—seal improvement, grease for wheel hub bearings, i) tyres of material molecular design, tread etc.

Fuel Consumption of car 2020 in a practical running condition

The fuel consumption of Car 2020 is calculated by using the predicted friction loss reduction rates while considering the threefold improvement and the retroactive effect. The calculated result shows that the fuel consumption for constant velocity running on a 0% slope is 3.09 L/100 km, which is a 49% less from that of Car 2010. i.e. 6.04 L/100 km of Car 2010.

Retroactive effect

As the tire rolling loss is reduced by 10%—the gears or bearings, the motive power that is transmitted by these elements' decreases, and thus, the friction losses of

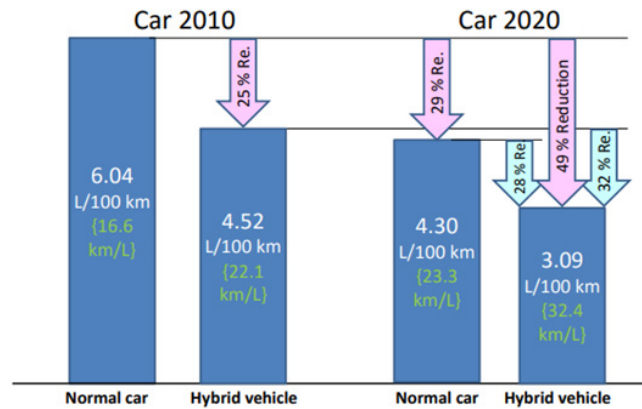


Fig-3: Comparison of fuel savings in a practical running with retroactive effect (Source: T. Nakamura, 2014)

these elements decrease. The calculated result shows that the fuel consumption is reduced by 2.77%, and this means that the contribution rate of the tire is 27.7% (T. Nakamura, 2014)

Impact of a Hybrid Electric Vehicle (HEV)

The main reason for the worldwide popularity of hybrid electric vehicle (HEV) is because it's a typical eco-friendly car. The comparison of performance as shown in Fig-3: a) The fuel consumption of HEV 2010 is lower by 25% with normal 'Car 2010', b) The fuel consumption of normal 'Car 2020' is less by 29% as compared to 'Car 2010' with the friction loss reductions as per tribology, c) The fuel consumption of HEV 2020 is lower by 28% as compared to normal 'Car of 2020' & d) By adopting the tribology, the researchers of Japan found the reduction of 32% in the fuel consumption of the HEV of 2020 (HEV 2020) as compared to that of (HEV 2010), (10-year-old) as shown

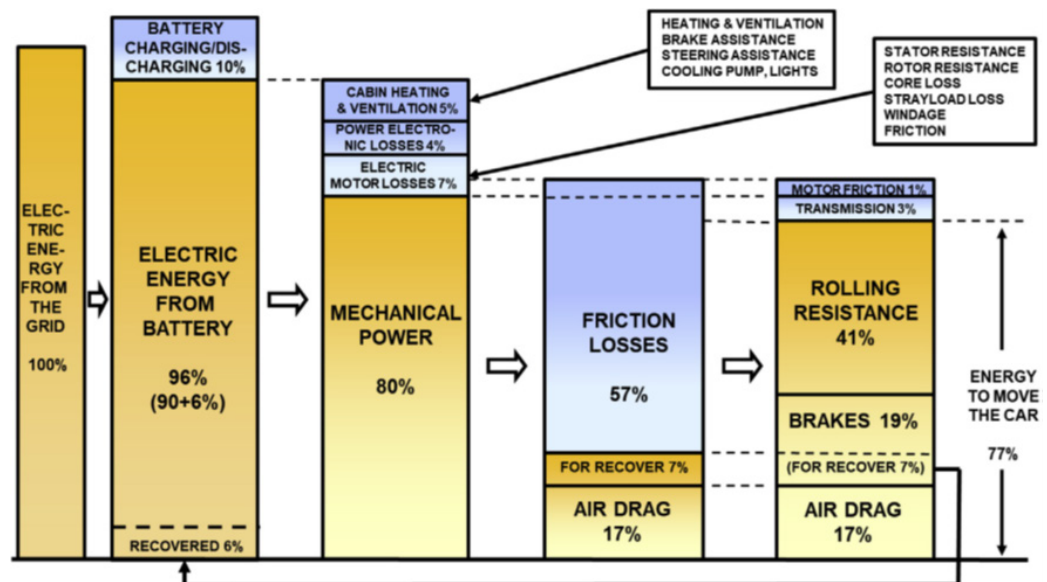


Fig. 4. Breakdown of the energy use in a battery electric (BEC) passenger car, of 2017 grid-to-wheel calculations (ref. K. Holmberg, Ali Erdemir et al.)

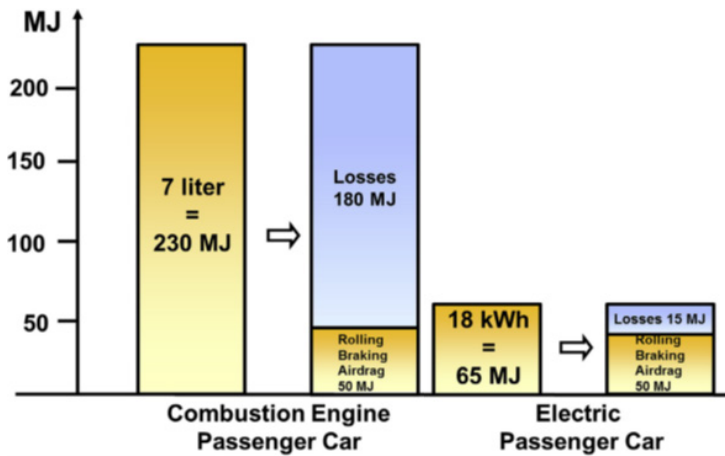


Fig-5. Energy consumption of global average internal combustion engine (ICE) and battery electric passenger cars (BEC) for 100 km driving, tank/grid-to-wheel calculations (ref. K. Holmberg, Ali Erdemir et al.)

in Fig-3 (T. Nakamura, 2014). This is indicative of the future of HEV & its performance in fuel consumption with that of a normal car.

Popularity of E-mobility

The battery electric car (BEC) need about 77% of energy to move and the remaining 23% of energy is used to overcome various energy losses (Fig-4). BEC differ from ICE vehicles in that the combustion engine is replaced by an electric motor, the mechanical transmission system is simplified, electricity storing, charging, and control systems are added and brake energy recovery systems are used. Due to regenerative braking, the kinetic energy is transformed back into electrochemical energy. This is shown as an extra 6% energy input in addition to the

100% electric energy coming from the grid and resulting in 106% energy to be consumed by the car, as shown in the second column from left in Fig-4. The number of e-vehicles will grow to 300 million worldwide by 2040, while at the same time, the number of vehicles with a combustion engine will rise from 1.3 billion to 2.1 billion vehicles (International Energy Agency estimate).

The energy efficiency for the BEC car is 77% which is 3.8 times higher, than 20% for the ICE car (Fig-4). For driving the same distance, the BEC uses only 18 kWh electricity. The rolling resistance is higher for the electric car due to its higher weight (considering additional weight of ~200 kg due to the heavy batteries), but the braking losses are smaller due to the energy recovery system. Finally, both cars require about 50 MJ (Fig-5) for running over 100 km but BEC incurs only 1/12th of ICE losses (Björnsson & Karlsson 2016, Jungmeier et al. 2015).

The whole impact of BEC is very challenging to the development of battery technology, smart charging stations and changes from fossil dominated fuels to renewable fuels.

Global energy consumption due to friction in Trucks, Trailers, Buses & Coaches

As per VAHAN data (MORT&H) of 2020, there are ~71 lakh such heavy-duty vehicles in India (1/50th of world). A comparison of the distribution of energy losses in these four vehicle categories is shown in Fig-6. In heavy duty vehicles ~1/3rd of the fuel energy is used to overcome friction in the engine, transmission, tires,

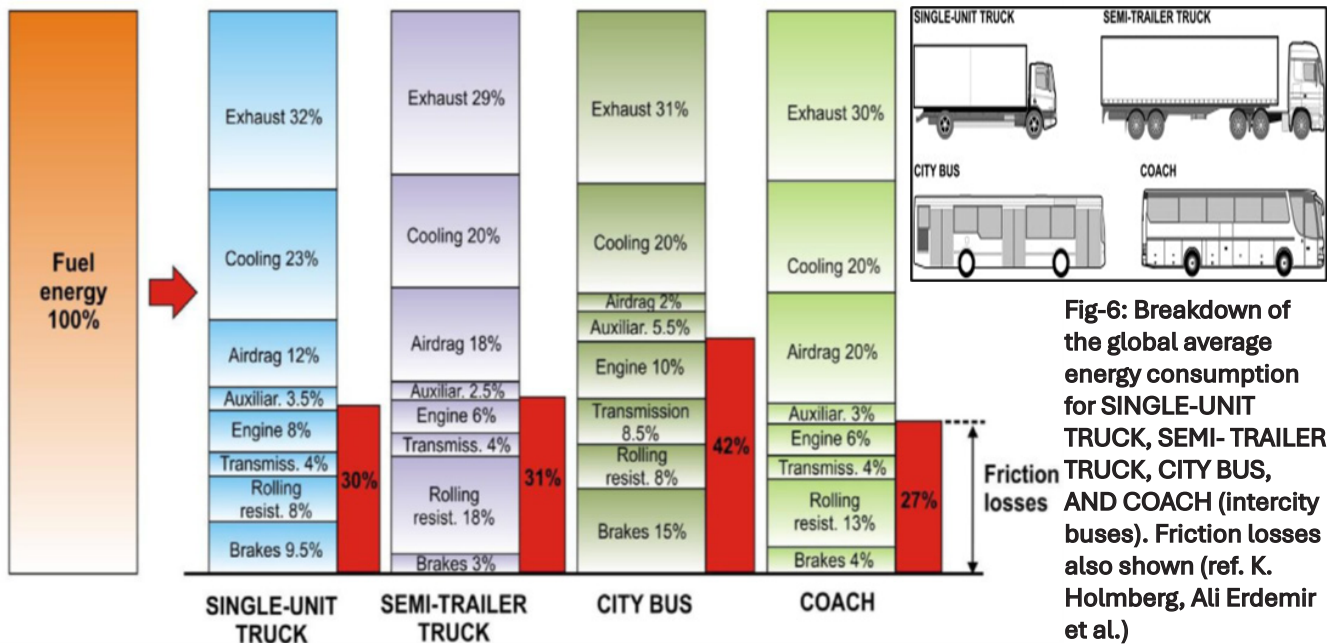


Fig-6: Breakdown of the global average energy consumption for SINGLE-UNIT TRUCK, SEMI-TRAILER TRUCK, CITY BUS, AND COACH (intercity buses). Friction losses also shown (ref. K. Holmberg, Ali Erdemir et al.)

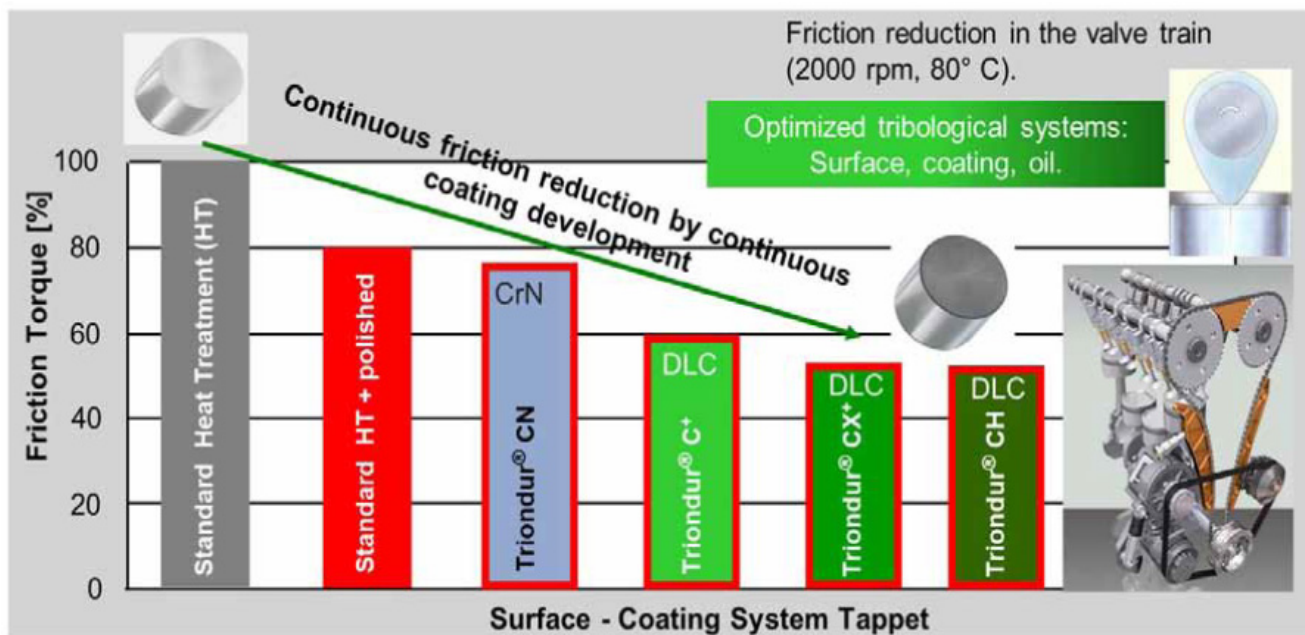


Fig-6: Measures reducing valve train friction (photo: SCHAEFFLER AG)

auxiliary equipment, and braking. 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. Reductions in friction losses provide additional advantages in fuel economy and exhaust and cooling losses are reduced as well. Electrification is best suited for city buses and delivery trucks.

Replacement of the traditional dual-tyre installations with wide-base to single tires leads to reduction of energy loss of several percent. The tyre pressure has a considerable effect on the rolling resistance. For truck tyres a 20% reduction in the pressure causes an increase of 5–8% in the rolling resistance and a 2–3% increase in the energy consumption. Battery electric buses are best suited for urban service. For commercial vehicles, the most common applications are city buses and delivery trucks. Interest in electric city buses is currently very high. Coaches and heavy long-haul trucks are not suitable for electrification unless systems are developed for continuous power supply (e.g., catenary or inductive).

New technologies to reduce friction and wear

Low friction coating: The coating applied on the components acts as a safety layer. The advantage of surface coatings has reported a 10-fold increase of fatigue lifetime in rolling contacts, a 7-fold reduction in bearing wear, and a 3-fold increase in gear lifetime (K. Holmberg et al). Most fuel injector plungers used in fuel delivery systems of modern diesel engines are now coated with a durable coating. The change from

traditional engineering materials like steel or cast iron to some polymeric, ceramic, or composite materials has been one solution to achieve low friction performance. Thin diamond-like carbon (DLC) and ceramic coatings are good examples of successful friction control technologies that can help to reduce friction coefficients to 0.001 level (Fig-7). **Super lubricity** is a sliding state with nearly zero friction, by definition with coefficients of friction below 0.01. Extremely low friction coefficients (even down to 0.0005) have been measured on nano and microscale with sliding surfaces involving highly hydrogenated and polymerlike DLC films, graphite, graphene and other 2D materials ((Kovalchenko et al. 2004, Klingerman et al. 2005, Ryk & Etsion 2006, Etsion 2012, Etsion & Sher 2009, Ishida et al. 2009, Vlădescu et al 2017)).

Changing the surface topography of gears by superfinishing has reduced friction by typically 30%. Fine particle peening of the contacting surface that produces a surface with micro dimples was also found to reduce friction in lubricated conditions by up to 50%. Tungsten carbide (WC, “hard metal”) has dominated wear protection for decades and is the standard material of choice for machining applications. Thus, tribology has impacted in reducing the friction & wear which contributed to energy saving in road transport industry. ♦

Prof. Kamal Mukherjee, a prolific science writer and nutritionist, is an active member of the Tribological Society of India and has held executive leadership roles in major national organizations. He can be contacted at kamalcbm28@gmail.com.