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Global energy consumption due to friction and wear in the mining industry

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ABSTRACT

Calculations on the global energy consumption due to friction and wear in the mineral mining industry are presented. For the first time, the impact of wear is also included in more detailed calculations in order to show its enormous tribological and economic impacts on this industry. A large variety of mining equipment used for the extraction, haulage and beneficiation of underground mining, surface mining and mineral processing were analysed. Coefficients of friction and wear rates of moving mechanical assemblies were estimated based on available information in literature in four general cases: (1) a global average mine in use today, (2) a mine with today's best commercial technology, (3) a mine with today's most advanced technology based upon the adaptation of the latest R&D achievements, and (4) a mine with best futuristic technology forecasted in the next 10 years. The following conclusions were reached:

- Total energy consumption of global mining activities, including both mineral and rock mining, is estimated to be 6.2% of the total global energy consumption. About 40% of the consumed energy in mineral mining (equalling to 4.6 EJ annually on global scale) is used for overcoming friction. In addition, 2 EJ is used to remanufacture and replace worn out parts and reserve and stock up spare parts and equipment needed due to wear failures. The largest energy consuming mining actions are grinding (32%), haulage (24%), ventilation (9%) and digging (8%).
- Friction and wear is annually resulting in 970 million tonnes of CO_2 emissions worldwide in mineral mining (accounting for 2.7% of world CO_2 emissions).
- The total estimated economic losses resulting from friction and wear in mineral mining are in total 210,000 million Euros annually distributed as 40% for overcoming friction, 27% for production of replacement parts and spare equipment, 26% for maintenance work, and 7% for lost production.
- By taking advantage of new technology for friction reduction and wear protection in mineral mining equipment, friction and wear losses could potentially be reduced by 15% in the short term (10 years) and by 30% in the long term (20 years). In the short term this would annually equal worldwide savings of 31,100 million euros, 280 TWh energy consumption and a CO_2 emission reduction of 145 million tonnes. In the long term, the annual benefit would be 62,200 million euros, 550 TWh less energy consumption, and a CO_2 emission reduction of 290 million tonnes.

Potential new remedies to reduce friction and wear in mining include the development and uses of new materials, especially materials with improved strength and hardness properties, more effective surface treatments, high-performance surface coatings, new lubricants and lubricant additives, and new designs of moving parts and surfaces of e.g. liners, blades, plates, shields, shovels, jaws, chambers, tires, seals, bearings, gearboxes, engines, conveyor belts, pumps, fans, hoppers and feeders.

1. Introduction

The global energy demand has been increasing steadily since the beginning of last century due to the growing societal needs and many diverse industrial activities. In the last 40 years, the world's energy demand has doubled and in the year 2013, the global final energy consumption increased by 2.3% from the previous year to around 9300 Mtoe (equalling to 390 EJ). Even though the development of renewable energy

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sources has been increasing, more that 80% of the total energy still comes from non-renewable fossil fuels like oil, coal and natural gas, which are the major contributors to greenhouse gas (GHG) emissions. In 2012, the energy use of the CO_2 emitting energy sources increased by additional 1.4% from the year before [103,105]; [20].

Mining is the search for, extraction, beneficiation, and processing of solid minerals from the earth's crust through open-pit mining, strip mining, quarrying and underground excavation. Mining has been an essential part of human activity for thousands of years to provide raw materials for improving security and quality of life as well as building the present-day industrial society. Some of the most important mining activities in our history have been the excavation for iron, gold, silver, copper, tin, lead, diamonds and coal for many Centuries. Minerals are defined as naturally occurring, stable at room temperature, represented by a chemical formula, biogenic and have an ordered atomic or crystalline structure. Even if coal does not by all means fit into the definition of minerals, the excavation of coal constitutes a major mining activity and hence is included in this study [45,46,221]. Rock excavation from quarry for civil engineering purposes is in some sources considered as mining because the activities involved are largely very similar but excluded in our study.

In general, a typical mining activity includes breaking, excavation, loading, hauling, transportation as well as mineral processing to reduce the size of large chunks of mineral containing rocks and to upgrade the concentration of these minerals by physical or chemical beneficiation methods. Mines are found in all parts of the world. The biggest producers of mineral raw materials (excluding petroleum and natural gas) are China accounting for 33.5% of the world mineral production, USA 12.0%, Australia 7.9%, Russia 7.1%, India 6.4%, South Africa 4.7%, Indonesia 4.0%, Brazil 2.1% and Canada 2.0 [192]. These numbers include production of ferrous metals, non-ferrous metals, precious metals, industrial minerals and solid mineral fuels like coal and uranium, but exclude oil and gas. Coal, in the forms of steam coal, coking coal and lignite, is the largest mining product measured by weight and representing about 60% of the total mining production. The second largest mining product is iron representing 11.4%, and next follows aluminium and bauxite 3.9%, salt 2.1%, sulphur 1.5%, gypsum 1.2%, phosphates 1.0%, manganese 0.14% and copper 0.13% [192].

There are many types and sizes of mines in the world, ranging from small surface quarries to large industrial underground mines, recovering ores at a depth of some kilometres beneath the surface. The deepest is a gold mine in South Africa operating at a depth of 4 km [212]. Most of the mining operations are surface mines, which include a variety of mines from large scale coal open-pit mines to small mineral or rock quarries. Still they all include the basic mining processes of drilling, detonating, comminution into manageable size, loading, transportation and further processing for end-use applications.

The mining activity is globally expanding due to the rapid urbanisation that creates a need for more metals and minerals in constructions and all kinds of consumer products, despite society's growing efforts in recycling and dematerialization. Another reason for this expansion is that the richest ores have long been used up so, at present increasing volumes of rock ore excavation is needed to extract the same amount of pure mineral. The demand for base metals, particularly iron, copper and aluminium, has been projected to double from 2010 to 2025, largely due to increasing global urbanisation and industrialization [3,170,187].

The total amount of energy used in the mining and minerals industry has been estimated to be 4–7% of the global energy output. The main energy sources are typically about one third electricity, one-third diesel oil fuel and one-third coal, natural gas and gasoline [186]. Largest amounts of energy are used in rock braking, crushing, grinding, loading, hauling and transportation. Pumping is also a large energy consumer and in underground mines, ventilation consumes significant amount of energy as well. Both friction and wear losses associated with the mining activities have a great influence on energy consumption in mining.

The impact of friction on the global energy consumption has recently been calculated for road transport by Refs. [61,90,93,94]. They 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 cars could be reduced by 18% within the next 5–10 years, which would result in global fuel savings of 117,000 million litres annually, and by 61% within the next 15–25 years, which would result in fuel savings of 385,000 million litres annually. These figures equal world-wide economic savings of 174,000 million euros in the next 5–10 years and 576,000 million euros in the next 15–25 years. These calculations were based on oil price level 2011. Such a fuel efficiency improvement in passenger cars would, furthermore, reduce CO_2 emission by 290 million and 960 million tons per year, respectively. This should have a significant positive impact on the global efforts to reduce the greenhouse gas effect and control global warming as overwhelmingly agreed by the world's nations at the 2015 Paris Climate Conference [220].

In another study [92], carried out similar calculations for one advanced manufacturing sector represented by paper production. In paper machines 32% of the electrical energy is used to overcome friction, 36% is used for the paper production and mass transportation and 32% is other losses. However, in a paper plant, the electrical energy is only 30% of the total energy consumption because the remaining 70% is process heating by steam. No other industrial sectors has been analysed in such details with regard to friction effect on energy consumption.

The paper production is by its nature much different from mining and mineral production, where the handling of heavy rocks and large quantities of solid materials in harsh, dirty and humid conditions form exceptional challenges. Unlike transportation and manufacturing, in mining, the wear-related energy losses are considerable and wear carries a greater importance as a source for energy consumption. To the best of our knowledge the impact of wear on energy consumption on industrial scale has not yet been adequately addressed in the past in any detailed study in the open literature.

Our earlier papers reviewed the global energy consumption due to friction in passenger cars, heavy duty vehicles and paper machines [90,92,93]. In this study we present calculations of the global energy consumption due to friction and wear and potential savings through the adaption of advanced friction and wear optimisation and control technologies in the mining industry. The focus is on the most energy consuming parts of mining, which is extraction, transportation and the mineral processing. Oil and gas extraction as well as rock excavation for civil engineering uses are excluded. Expected changes and trends, such as automation, remote operation, advanced processing, globalisation and market prices like supercycles [3,170,187], are not included in the present analyses.

2. Methodology

This work was carried out by a methodology previously developed by Refs. [90,93] for calculation of global impact of friction on transportation. Now it was extended to also include wear calculations. The methodology is based on the combination of analyses on several physical phenomena resulting in the energy consumption in mechanical equipment. It includes the following analyses and calculations:

1. An estimation of the global energy consumption by mining industry.
2. Calculation of the friction, wear and energy losses in three major categories of mining units (underground mine, surface mine, and mineral processing).
3. Estimation of operational effects in the three mining categories.
4. Estimation of tribocontact-related friction and wear losses today and in the future.
5. Calculation of the global energy consumption today due to friction and wear losses and potential savings.