The "SCOOP" ON THE WORLD'S FIRST HYBRID MINING LOADER

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Abstract

Researchers at Natural Resources Canada (NRCan) CANMET Mining and Mineral Sciences Laboratories (CANMET-MMSL) and Mining Technologies International (MTI) have designed and built a hybrid diesel-electric mining loader that is the first of its kind to be developed for underground mines.

Diesel equipment is popular because of its mobility and most mining operations are reluctant to replace it with tethered electrical equipment despite the obvious elimination of diesel contaminants and significantly lower heat generation (˜ 35% of an equivalent diesel). However, a diesel-electric vehicle, being currently evaluated by CANMET-MMSL, could be beneficial. In this unit, a constant load diesel generator feeds batteries which, in turn, powers electrical motors that drive the equipment. In a hybrid diesel-electric unit, the constant load diesel generator can be optimized for minimal emissions and hence lower dilution air requirements.

This paper will present the project status and the anticipated benefits for mining operations through the application of this technology.

1. Introduction

In mining, diesel emission control is important in terms of both the health of mine workers, and the management of the mine ventilation network. Mine ventilation is a major consumer of energy in an underground mining operation. Any technological advancement improving the underground air quality, including the development of low-emission vehicles, would reduce ventilation demand, and likewise, reduce costs, and energy consumption and the associated greenhouse gas emissions.

The objective of the project is to build, test and market a 1.15-m^3 Hybrid – Load-Haul-Dump (H-LHD) prototype and verify the potential of the hybrid diesel-electric technology for handling ore and waste rock material in underground mines. CANMET Mining and Mineral Sciences Laboratories (CANMET-MMSL) and Mining Technologies International (MTI) are mainly responsible for engineering design, testing and optimization, and environmental studies. Testing will be carried out at the CANMET-MMSL Experimental Mine in Val-d'Or, Quebec. Subsequent performance testing of the prototype is planned at three Canadian mines and one American mine. If the hybrid diesel-electric technology proves to be reliable and efficient for underground applications, a full line of hybrid mining equipment could potentially be developed and the technology could be marketed. This project is a collaborative effort by the following partners:

- Mining Technologies International (MTI);
- CANMET Mining and Mineral Sciences Laboratories (CANMET-MMSL);
- Société de recherche et de développement minier (SOREDEM);
- The Government of Canada;
    - Action Plan 2000 on Climate Change, Mineral and Metals Program;
    - NRCan's Industry Energy Research and Development (IERD) Program;
- Hydro-Québec;
- The Diesel Emission Evaluation Program (DEEP); and
- Participating mines.

This paper describes the concept behind the "Hybridisation of a Load-Haul-Dump Mining Vehicle Project" and presents the results of two studies carried out by CANMET-MMSL. One of the studies estimated the potential of Greenhouse Gas (GHG) reduction anticipated following the application of the hybrid electric-diesel technology for the Canadian mining industry. The second one focused more specifically on the estimation of electrical energy savings for Quebec mines.

2. Hybrid Diesel-electric LHD

There are two types of hybrid diesel-electric configurations available on the market: serial and parallel. The serial configuration has been selected for the current project because it offers the best potential for diesel emission reduction.

The engine initially selected for the prototype was a Deutz F2L 2011. This engine is among the least polluting available in the 15-22 kW range. Tests performed by the CANMET-MMSL Underground Mine Environment Program showed that this engine has the lowest emissions per horsepower for all high load operating points at speeds between 2,000 and 2,800 RPM.

The power generated by the F2L 2011 engine, when operating at 2,000 RPM with a 90% load, is 15 kW. It was estimated, through numerical simulations, that 15 kW is sufficient to accomplish most typical duty cycles. Although the F2L 2011 engine is theoretically powerful enough, it was decided to use a more powerful engine in the prototype. Therefore, the F3L 2011 model, a 3-cylinder electronic EMR version of the same engine, was selected and justified for the following reasons:

- Additional power availability if the system is not as efficient as expected;
- Comparative emission levels;
- Lower fuel consumption;
- Lower demand on the batteries in peak segments of the duty cycle.

Once the trial period is completed, the engine size will be modified if proven to be overdesigned.

In the actual configuration, the diesel engine is not mechanically linked to the vehicle's transmission, allowing the engine to operate at a constant speed. The diesel engine directly drives the hydraulic pumps and an electric motor/generator via a pump drive. The purpose of the electric motor/generator is to charge the batteries and supply power to the traction motor. It can also assist the diesel engine during peak hydraulic loads.

An electric traction motor is attached directly to a 3-speed mechanical transmission. In a conventional diesel-powered LHD, a torque converter converts engine RPM into torque when necessary. The efficiency of the torque converter varies between 0% and 83% depending on speed/load conditions. In the hybrid prototype design, no torque converter is required because the electric motor can supply sufficient torque at low speed. Removing the torque converter from the system represents a significant efficiency improvement.

Additional energy savings could have been achieved by removing the mechanical transmission if an electric motor offering an appropriate torque/speed profile could have been found. However, keeping the mechanical transmission offers the advantage of being able to operate the electric motor in its most efficient operating range.

The best option for the current application is a NiMh battery pack. The main advantage of these batteries is the high energy to volume ratio. The prototype being developed is one of the smallest LHDs (1.15 m^3) on the market and therefore space is limited. In order to obtain the required power, three battery packs, from an existing model, are connected in parallel.

During the testing and optimization phase, adjustments and/or modifications will be made to the prototype in order to increase its efficiency and reliability. All of the optimization will be done while trying to keep diesel emissions to a minimum.

Furthermore, environmental studies will be carried out by comparing the level of diesel emissions produced by the hybrid loader prototype with those of a conventional mine loader. After the collected data is analysed, the CANMET-MMSL Underground Mine Environment Program will determine the proper size of the exhaust purifier for an additional reduction in diesel emissions.

After the trial period at the Experimental Mine, the equipment will be tested in four different mines for a four-month period at each mine. The companies that have agreed to participate are: Agnico-Eagle, Kirkland Lake Gold, Goldcorp Inc. and Stillwater Mining Company.

3. Impact of hybrid diesel-electric equipment on underground mining operations

Underground mine operators are constantly dealing with diesel emission control. The development of less polluting and less consuming equipment would represent a great opportunity to make progress on sustainable development, energy efficiency and workers' health. In the short and medium-term, the hybrid diesel-electric technology applied to an underground vehicle could be part of the solution.

The improvement of underground air quality could reduce ventilation demand and likewise reduce energy consumption and the associated greenhouse gas emissions. The use of such equipment would improve the global image of the mining industry and have a direct economic impact on operations.

In a Canadian context, the electrical consumption required to operate a ventilation system generally represents between 30% and 50% of the overall energy costs of an underground mine. In addition, during the cold season, the air must be heated by using gas-fired systems (propane or natural gas).

The next two sections summarize the results of two studies carried out by CANMET-MMSL. The first one estimates potential GHG emission reductions in a Canadian mining context and the second one evalutes specific electrical energy savings for Quebec mines. Both studies are based on the assumption that all diesel equipment is replaced by hybrid equipment.

3.1 GHG emission reduction implications in a Canadian context

In order to evaluate the impact of hybrid mining vehicles on GHG emissions, 44 mines listed in the *2004 Mining Sourcebook* (pages 83 and 84) using trackless equipment, were considered. These are the targetted mines for the introduction of hybrid mining equipment. The impact on GHG emissions is related to reductions in vehicle diesel fuel consumption, electrical consumption to ventilate the mine, as well as the fossil fuel required to heat the mine during the winter season.

In order to estimate the electrical consumption of the main ventilation system, the rated power of each fan was taken from the *2004 Canadian Mining Sourcebook*. It is assumed that all fans are loaded to 80% of their rated power and that they run 24 hours a day for 365 days. Unfortunately, the same data was not available to estimate the power consumption of the auxiliary fans, fuel consumption for heating or diesel fuel consumption of the fleet of vehicles in each mine. The missing data was estimated by using ratios calculated from data collected in 5 mines studied in detail in a previous study (C. Kocsis, 2003). The calculated ratios are presented in Tables 1 to 3.

Table 1 – Auxiliary to main ventilation ratio estimation

	Main (kW/year)	Auxiliary (kW/year)
Creighton	6,818,000	27,273,000

Seleine	5,174,100	8,012,300
LaRonde	9,917,350	38,615,700
Niobec	4,236,100	8,351,600
Doyon	7,803,900	35,842,300
Total:	88,949,450	35,842,300
kWh Ratio (aux/main): 1.3277 (It is assumed that the auxiliary ventilation electrical consumption is proportional to the main ventilation electrical consumption.)		

Table 2 – Propane consumption to ventilation volume ration estimation

	Main (m^3/s)	Propane (litres/year)
LaRonde	703	2,028,570
Niobec	289	1,700,000
Doyon	345	1,262,420
Total:	1,350	4,990,990
Ratio of propane litres/ m^3/s: 1.7439 (It is assumed that fuel consumption for heating is directly proportional to mine airflow.)		

Table 3 – Diesel consumption to ventilation volume ratio estimation

	Main (m^3/s)	Diesel (litres/year)
Creighton	608	1,900,000
Seleine	142	694,861
LaRonde	703	2,123,374
Niobec	289	520,000
Doyon	345	594,900
Total:	1,350	5,833,135
Ratio of diesel litres / m^3/s: 1.3108 (It is assumed that fuel consumption is proportional to mine airflow.)		

In the Kocsis study, it was determined that fuelcell vehicles would allow a 9% airflow reduction with workings located below a 2,425-meter depth and 24% with workings located at a depth in the range of 400 to 800 meters. As discussed with the author, that reduction could also be applied in mines wanting to replace their existing equipment with hybrid vehicles. Due to the fact that there is a cubic relationship between airflow and electrical consumption, the author estimated that electricity consumption for the main ventilation system could be reduced by 24% to 53%. The auxiliary ventilation system works separately and its electrical consumption cannot be reduced by the same ratio as the main system in order to maintain proper working conditions. Therefore, the reduction in auxiliary ventilation was estimated at 20% for all mines, which is an average value obtained for the mines investigated in the Kocsis study. Furthermore, the reduction in mine heating is the same as estimated for the main airflow. These reduction factors are applied to each mine in this evaluation.

Another impact of hybrid vehicles is the reduction in diesel fuel consumption related directly to the use of a smaller engine, combined with a more energy efficient system. The reduction was estimated at 25% to 35% in a study carried out for the ''Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST)''. In the estimation presented, an average value of 30% was used.

All these reductions in energy consumption (electricity, heating fuel, diesel) have been calculated per province using their specific CO_2 equivalent factor to produce electricity. These factors were obtained from the Environment Canada official website.

Assuming the replacement of the entire fleet of underground mining vehicles with hybrid vehicles, the overall potential GHG emission reduction is estimated to be 28.4%, as shown in Table 4. This evaluation takes into consideration the reduction in GHG emissions that is related to electricity, diesel fuel and other fossil fuel required to heat the incoming air. The summary of GHG emission reduction is presented by province and territory.

Table 4 - Summary of GHG emission reductions in Canada

Province/Territory	**Electricity savings** tonnes/yr of CO_2e	**Heating energy savings** tonnes/yr of CO_2e	**Mining vehicle diesel fuel savings** tonnes/yr of CO_2e	**TOTAL GHG emission reduction** tonnes/yr of CO_2e
British Columbia	80	160	300	540
Manitoba	890	4,860	9,290	15,040
New Brunswick	18,050	2,040	3,900	23,990
Nova Scotia	520	160	310	990
Nunavut	1,410	440	840	2,690
Ontario	20,100	7,100	15,210	42,410
Quebec	40	2,570	5,320	7,930
Saskatchewan	9,700	1,230	2,350	13,280
Northwest Territories	280	80	150	510
	51,070 **47.6%**	**18,640** **17.4%**	**37,670** **35.0%**	**107,380** **28.4%**

Energy savings and GHG emission reductions are mainly associated with the ventilation system electrical consumption (47.6%) and with a reduction in diesel fuel requirements (35.0%). Fuel for heating has a less significant impact on emission reductions because the fresh air is heated only during the cold season. It is important to mention that there are a few Canadian mines that are cooling air during summer months to improve working conditions. This factor was not considered in this evaluation because of the lack of information and in view of the fact that only a few mines use a cooling system.

3.2 Specific electrical energy savings estimated for Quebec mines

A total of ten (10) Quebec mines were asked to provide recent data on their ventilation systems and their diesel equipment in use. While assuming that all underground diesel equipment is replaced by hybrid equipment, it was also assumed that all types of equipment had the same energy consumption patterns as LHDs. That assumption should be studied in depth for all types of vehicles used underground in order to obtain a higher degree of accuracy in terms of ventilation requirements.

According to a CANMET-MMSL study, the airflow could be reduced by 35% using hybrid equipment if no other factors needed to be considered. Generally, as the mine gets deeper, heat becomes the limiting factor for airflow requirements. Even when the equipment is emission-free, a minimum airflow must be maintained to eliminate blast fumes and dust, and to control heat levels and maintain air speed above 0.5 m/s.

In order to calculate the electrical consumption reduction associated with airflow reduction, it is important to estimate the electrical consumption of the primary and secondary ventilation systems separately according to the specific configuration of each mine. This detailed exercise was done in the Kocsis study for two of the Quebec mines. For the other mines, the electrical consumption was estimated as a function of the nominal force, the load and the annual operating time of the fan provided by the participating mine operators.

The results illustrated in Table 5 show a 20% reduction in ventilation requirements brought by the introduction of hybrid diesel-electric equipment. Consequently, a reduction in electrical consumption between 18% and 41% can be achieved, depending on the mine. The overall yearly reduction was estimated at 49.33 GWh for Quebec mines.

Table 5 – Estimation of the reduction in electrical consumption for underground Quebec mines

Mines	Airflow	Potential reduction	Electrical consumption reduction				
	m^3/s	%	Primary ventilation %	Secondary ventilation %	Cooling %	Global %	Global GWh
Casa Berardi	330	20	45	20		32.3	5.81
Doyon	360	22	53	19		25.1	1.09
Goldex (projection)	189	20	52	20		41.3	3.64
Lapa (projection)	142	20	45	20		32.8	5.95
LaRonde	703	14	36	16	14	18.7	11.72
Niobec	289	20	45	20		28.4	3.58

Seleine	142	20	45	20		29.8	3.93
Bell [1]	153	20	n/a	n/a	n/a	n/a	3.25
Kiena [1] (projection)	24	20	n/a	n/a	n/a	n/a	0.50
						Total:	49.33

[1:] Electrical consumption estimated from the average value obtained from the other mines.

4. Conclusion

The introduction of hybrid equipment in the mining industry would be beneficial to the health of workers, the profitability of operations and the environment. The hybridisation of a Load-Haul-Dump (LHD) mining vehicle is progressing well. The prototype should be ready for testing at the CANMET-MMSL Experimental Mine at the end of June 2008. The trial period will allow to evaluate and improve the efficiency and reliability of the prototype, while keeping diesel emissions to a minimum.

Based on the available data, the introduction of hybrid diesel-electric equipment in underground mines has the potential of reducing GHG emissions by 32%. This represents 119,930 tonnes a year of CO_2 equivalent for the Canadian mining industry. The potential improvement is mainly associated with the reduction in electrical consumption related to mine ventilation (47.6 %) and in fuel consumption (35.0 %) by using smaller engine.

Regarding the specific study on potential electrical energy savings in Quebec mines, results showed reductions ranging between 18% and 41%, depending on specific mine configurations.

5. References

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