NO_x emission of equipment and blasting agents in surface coal mining

by A. Lashgari, C. Johnson, V. Kecojevic, B. Lusk and J.M. Hoffman

Abstract ■ Surface coal mining in the Appalachian region consumes a significant amount of energy in the form of diesel fuel and blasting agents. Emission of oxides of nitrogen (NO_x) from these sources represents an environmental challenge to the mining industry. This paper presents the results of research work related to determination of NO_x emission of mining equipment and blasting agents, which is part of a broader industrial project conducted by the Appalachian Research Initiative for Environmental Research (ARIES). Data for this project are collected from an operating surface coal mine in West Virginia. The research work presented here may be used by mining professionals to aid in quantifying NO_x emission and determine strategies for reducing its overall environmental impact.

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Introduction

The primary substances emitted from combustion engines include: carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x), particulate matter (PM), sulfur dioxide (SO_2) and volatile organic compounds (VOCs). The NO_x is a group of highly reactive gasses such as nitric oxide (NO) and nitrogen dioxide (NO_2). They are toxic chemicals that help form acid rain and hamper the growth of plants. They also contribute to the creation of ground-level ozone. In combination with some other substances, NO_x can cause major human respiratory problems, and may lead to shortness of breath, irritated nose and eyes, nausea and fluid forming in lungs (Konac, 2004). A high amount of NO_x can cause visual impairment, reduced oxygen intake, a larger buildup of fluids in lungs, swelling of throat, rapid burning spasms and even death (Baukal, 1998).

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In order to avoid potential human and environmental problems, the U.S. Environmental Protection Agency (EPA) established standards for NO_2 emission in 1971. A primary standard (to protect health) and secondary standard (to protect the public welfare) were set at 0.053 parts per million (ppm), averaged annually (EPA, 2012). In 2010, the EPA established an additional primary standard at 0.1 ppm, averaged over one hour (EPA, 2012).

Surface coal mining unit operations include drilling, blasting, loading and haulage. Various mining equipment and blasting agents are used in these operations, and they are also a dominant source of NO_x emission. The objective of this research was to determine NO_x emission of mining equipment and blasting agents for a specific surface coal mining operation in the Appalachian region. The text that follows provides a background to NO_x emission from mining equipment and blasting agents, description of the methodology used in this study, results, analysis of obtained results and concluding remarks.

Background to NO_x emission from mining equipment

There are several estimation methods that can be used to determine the amount of NO_x emission. These methods include: direct measurement or sampling, mass balance, fuel analysis and emission factors (NPI, 2008). Direct measurement uses continuous emission monitoring or sampling data from the working area. In the mass balance method, the difference between the amount of a specific substance in the output and the amount in the input of the system is used to calculate the emission of a specific pollutant. The fuel analysis method is based on chemical or physical properties of a substance (e.g., ideal gas law) and application of the set of mathematical relationships. The emission factors method is commonly used for estimating exhaust emissions. This method is based on multiplication of the activity rate (in units of weight, volume, distance or duration per unit of time) by the appropriate emission factors. Emission factors are expressed as the average emission rate when a unit of equipment is operated in an average manner (i.e., load). These factors are usually mass-based and stated in units of mass per unit of fuel consumed, mass per unit of activity (e.g., pound per horsepower hour) or mass per mile traveled.

Several studies have been conducted to determine exhaust emissions for construction and mining equipment. Gautam et al. (2002) conducted a study to determine the exhaust emission for off-road equipment, focusing on front-end loaders, street sweepers, excavators and bulldozers. Emission factors have been established based on the field data. Frey et al. (2010) published results of a comprehensive field study on fuel consumption and emissions of nonroad diesel construction equipment. Kecojevic and Komljenovic (2010, 2011) studied the impact of engine load factors on fuel consumption and CO_2 emission of haul trucks and bulldozers, while Bogunovic and Kecojevic (2009) presented the results of research work related to the determination of CO_2 emissions from surface equipment in an operating surface coal mine in the southern United States. Lewis (2009) conducted research related to the emission of backhoes, bulldozers, excavators, motor graders, off-road trucks, track loaders and wheel loaders. The author estimated that, in 2008, the annual NO_x emission of this equipment was approximately 56% of the total NO_x emitted by all equipment used in construction and mining projects. Kean et al. (2000) presented a method for a fuel-based determination of NO_x emission for off-road diesel engines at regional and national levels.

The NONROAD model developed by EPA (2004) provides an equation for determination of equipment emission as follows:

$$E = N \times HP \times LF \times EF \times A \quad (1)$$

where E is emission amount (kg/a), N is engine population for a given base year (year of 2000 for mining equipment), HP is engine power (kW), LF is load factor (%), EF is emission factor (kg/kW-hr) and A is activity rate (hr/a).

Engine populations in the NONROAD model are classified by fuel type, application and power level. In the case that engine activity rate and engine load factor are not known, default input values suggested by the NONROAD model can be used (EPA, 2010).

EPA (1985) presents emission factors for heavy-duty, diesel-powered mining and construction equipment in lb/hr, lb/kWh, lb/hph and lb/gallon. The National Pollutant Inventory (NPI) Agency in Australia has also established the same values for exhaust emission factors of surface mining equipment (NPI, 2002; NPI, 2008).

Background to NO_x emission from blasting

NO_x emissions from blasting are released rapidly in relatively high concentrations that can dissipate out of the mine area in toxic plumes of gas. Due to the extensive use of blasting agents used in mining and increasing constraints with respect to their environmental impacts, it is important to have a gauge on the quantity of toxic fumes generated.

As an oxygen balanced explosive, such as ammonium nitrate/fuel oil (ANFO), detonates, a large quantity of expanding hot gases are produced. In an ideal situation, only hot steam, carbon dioxide and nitrogen are produced.

$$3NH_4NO_3 + CH_2 \Rightarrow 3N_2 + CO_2 + 7H_2O \quad (2)$$

In reality, efficient blasting practice is only possible with sufficient confinement and priming. Furthermore, the explosive products are often contaminated with water and drill cuttings, all of which affect the explosive quality and chemical kinetics. This results in nonideal explosive reactions and production of toxic gases: nitrogen dioxide, nitric oxide and carbon monoxide (NO_2, NO and CO), as well as a reduction in energy imparted onto the rock mass. The concentrations immediately dangerous to life or health (IDLH) for NO_2, NO and CO are 20, 100 and 1,200 ppm, respectively (NIOSH, 1994). NO_x consists of multiple of species of nitrogen and oxygen (N and O) in varying combinations, including N_2O, NO, NO_2, N_2O_2, N_2O_3, N_2O_4 and N_2O_5. NO_2 is the primary component of the NO_x series, but for the purpose of this research, NO_x will refer to the sum of pounds of NO and NO_2. Explosives are often contaminated with ground or rain water, leading to increased levels of NO_x gases through the breakdown of ammonium nitrate into nitrate and ammonia in solution. The desensitized solution will not fully decompose when detonated, producing nonideal products. The under and over fueling thus produced will be an explosive mixture, resulting in positive and negative oxygen balances, respectively. A positive oxygen balance will produce more NO_x gases, while a negative oxygen balance will produce more CO.

Effect of over fueling ANFO is:

$$2NH_4NO_3 + CH_2 \Rightarrow 2N_2 + CO + 5H_2O \quad (3)$$

Effect of under fueling ANFO is:

$$5NH_4NO_3 + CH_2 \Rightarrow 4N_2 + 2NO + CO_2 + 7H_2O \quad (4)$$

Nitric oxide is unstable in air and reacts with oxygen to produce the more toxic nitrogen dioxide, which can be seen after a blast by the generation of an orange/brown cloud (Onederra, 2012):

$$2NO + O_2 \Rightarrow 2NO_2 \quad (5)$$

For every 1 kg (2.2 lbs) of ammonium nitrate that is diverted along a reaction path similar to that above, more than 113 L (30 gal) of NO_x will be generated. In a worst case scenario of no added fuel, theoretically 1 kg (2.2 lbs) of ammonium nitrate can generate about 605 L (160 gal) of NO_x (AEISG, 2011). This calculation shows that only a small fraction of the explosive reacting in the wrong way can produce noticeable volumes of NO_x gases. Even in a perfectly oxygen balanced explosive mixture, NO_x could be produced if other contaminants, such as drill cuttings, prevent ammonium nitrate fully decomposing through to nitrogen, by slowing down the velocity of detonation (VoD), causing deflagration instead of detonation.

Toxic fumes are not always considered within environmental licenses but annual emissions of NO_x should be estimated at each mine. Estimates are calculated by multiplying the total annual amount of explosive consumed by a chemical product factor. EPA suggests 5.8 L of NO_x per kilogram of explosive (17 lb of NO_x per st of ANFO (lb/st)); however, no

Table 1

Range of product factors for ANFO and emulsion.

Authors	ANFO		Emulsion	
	Lowest product factor (L/kg)	Highest product factor (L/kg)	Lowest product factor (L/kg)	Highest product factor (L/kg)
Chaiken et al. (1974)	-	7 Under fueled	-	-
Mainerio (1997)	2.5 6% Fuel oil	4.8 Under fueled	-	-
Rowland and Mainerio (2000)	2 No water	9.9 Under fueled	-	-
Rowland et al. (2001)	-	-	2.7 No water	5.5 Water: one week
Sapko et al. (2002)	11 Confinement: steel pipe	36.5 Confinement: galvanized sheet metal	4.2 Confinement: steel pipe	6.2 Additive: drill cuttings

conversion factor is available for emulsion. This conversion factor is based on the chemical composition of the explosive and does not take into account other properties, such as rate of detonation, explosive composition, priming or confinement. Since an ideal chemical composition will not produce any NO_x, it is unknown what chemical composition is used to calculate the product factor; in addition, the number has not been updated since 1980, so is subject to high uncertainty (EPA, 2011).

Factors affecting the emissions from explosives detonation are difficult to measure accurately in the field and almost impossible to duplicate in lab scale tests. Currently, almost all tests have been carried out in laboratory test chambers that differ significantly from the actual environment where surface mine blasting takes place.

An ideal way of measuring toxic fumes produced from a blast would be to sample the atmosphere after a typical blast takes place. This is, however, impractical, as the fumes will not be confined for a long enough period of time to be accurately sampled, and there is no such thing as a "typical blast" (Rogers et al., 1977; Abata et al., 1978). In addition, research has shown that the degree of confinement of an explosive charge and the material being blasted have significant impact on fume production. Therefore, measurement of fumes at one mine location may not give a good indication of fumes at a different blast location, pattern or material.

A facility was established at the Pittsburgh Research Center's Experimental Mine that has the ability to detonate large, confined charges in a controlled volume (Mainiero, 1997). A blasting agent fumes test is described involving a 0.69-m (27-in.) length of 0.1-m (4-in.) schedule 80 seamless steel pipe or 0.1-m- (4-in.-) diameter galvanized sheet metal pipe for confinement. A velocity probe was taped to the inner surface before being loaded with 4.54 kg (10 lbs) of explosives charge. Initiation was achieved using a 0.076-m- (3-in.-)-diameter, 0.025-m- (1-in.-) thick cast pentolite booster initiated by a number eight instantaneous electric blasting cap. Fans are equipped within the chamber to mix the atmosphere and fume samples taken through 0.0064-m (0.25-in.) Teflon tubes for analysis. This was the first small-scale test that had detonation velocities similar to that measured in the field, of 4,000 m/s.

Mainiero (1997) carried out a number of tests at the experimental mine, looking at NO_x emissions as a function of fuel oil content in ANFO. Results were compared to previous tests from Chaiken et al. (1974) and Persson and Persson (1980), and predicted values for an ideal blast by Chaiken et al. (1974). As expected, the lowest levels of NO_x occur at an optimum ANFO ratio of 94/6. Comparison to other data, however, had little correlation, and it was concluded that a standard technique, through testing or computer modeling, needed to be established.

Exploratory laboratory-scale studies were carried out by the U.S. National Institute for Occupational Safety and Health (NIOSH) to determine factors that contribute to the production of nitrogen oxides associated with the nonideal detonation of ANFO in the Pittsburgh Research Center's Experimental Mine (Rowland and Mainiero, 2000). Degree of confinement, water contamination, oxygen balance, aluminum content and the addition of rock dust were tested at an optimum fuel oil content of 6%. The addition of water, confinement and rock dust were found to significantly increase NO_x production, as does a decreased oxygen balance, but aluminum, often added to ANFO to increase velocity and output energy, had no effect.

Rowland et al. (2001) published a second paper regarding NO_x emissions from emulsion and ANFO/emulsion blends when exposed to water for prolonged periods of time. Tests were completed at the Pittsburgh Research Center's Experimental Mine. Blends of 70/30 and 50/50 ANFO/emulsion and emulsion were tested after being exposed to water for one day, one week, one month and two months in steel and galvanized sheet metal. For comparison, explosives were also tested with no exposure to water. Results show that 70/30 blends exposed to water for longer than a week failed to detonate, and those confined with galvanized sheet metal failed after exposure for just one day. It has been noted that blends with 30% emulsion are not sufficient to make it waterproof, and 50% emulsion can only be exposed for short periods of time. Results produced by Rowland et al. (2001) agree with Schettler and Brashear (1996) that 50/50 bends are water resistant for short exposures but not for exposures of one week or more. Since it is known that emulsion blends should not be exposed to water for long periods of time but are only suitable for loading into wet holes, NO_x emissions from other contaminants such as drill cuttings, priming and confinement should be further investigated to get a full understanding of the emissions from emulsion blends in order to produce a feasible product factor for surface mine operations. NO_x emissions for emulsion peaked at an exposure to water for one week, so prolonged contamination with water will not continue to increase NO_x emissions.

Sapko (2002) conducted an exploratory laboratory-scale study into factors that contribute to NO_x production, identifying that admixture with drill cuttings, loss of fuel oil in ANFO from wicking, ammonium nitrate dissolution with water, degree of confinement, ANFO density and critical diameter all contribute to increased NO_x levels. Experiments to determine the effectiveness of additives to reduce NO_x production were also conducted, concluding that aluminum powder, coal dust, urea and excess fuel oil in ANFO all reduced NO_x production. ANFO, emulsion and emulsion blends were all tested.

Table 1 shows a summary of the highest and lowest product factors in L/kg taken from the current literature on NO_x emissions from blasting ANFO and emulsion, along with the contaminant tested.

Product factors for ANFO range from 2-36.5 L/kg (6.4-112.9 lbs/st) and from 2.7-6.2 L/kg (8.6-24.6 lbs/st) for emulsion. The highest product factors for all authors come from under fueled mixtures of ANFO or very heavy confinement. High NO_x emissions from emulsion are from water exposure for one week and the addition of drill cuttings. However, it should be noted that fewer contaminants have been tested with respect to emulsion and the range is based on fewer sources.

Methodology

Data for this project was collected from an operating surface coal mine in West Virginia. The mine has been active since the early 1970s. The geologic formations in the mine consist of sandstone overburden, with some shale streaks, five coal seams of varying thicknesses interspersed between layers of interburden. The mine produces approximately 2.54 Mt (2.8 million st) of coal and about 32 Mm^3 (42 million cu yd) of overburden per year. The operation uses diverse mining equipment: dragline, cable (electric) shovel, drills, bulldozers, hydraulic shovel, graders, haul trucks, front-end loaders, water trucks and various auxiliary equipment.

Data on fuel consumption and number of working hours for all mining equipment were obtained from the mine and sorted in Excel spreadsheet. Data is classified for eight drills, 14 bulldozers, a hydraulic shovel, three graders, 32 haul trucks, nine front-end loaders, as well as two water trucks. Dragline and cable (electric) shovels are also used for overburden removal, but they are omitted from further consideration since they consume electricity in their process.

For the purpose of this study, the emission factors method is applied, and the NO_x emission for mining equipment has been determined as follows:

$$E_{NOx} = EF \times HFC \times A \quad (6)$$

where E_{NOx} is annual NO_x emission of the equipment (kg/a), EF is emission factor (kg/L), HFC is hourly diesel fuel consumption (L/hr) and A is number of operating hours per year (hr/a). Values of emission factors (Table 2) were adopted from NPI (2002, 2008) and EPA (1985). Since no data on the production rate for trucks, hydraulic shovel, bulldozers, wheel loaders and other equipment were available, the amount of NO_x emission per t or m^3 of mined material could not be determined.

Table 2

Values of emission factors (*EPA 1985 and NPI 2002; **NPI 2008).

Equipment	Emission factor (kg/1,000 L)
Bulldozer*	34.16
Hydraulic excavator*	30.73
Drill**	23.30
Grader*	30.41
Haul truck*	34.29
Water truck*	40.73
Front end loader*	38.50

Explosives usage was also available for this surface coal mine. The mine uses ANFO and emulsion in quantities of 11,125 t (12,263 st) and 11,825 t (13,035 st), respectively. Minimum and maximum product factors were taken from Table 1 for ANFO and emulsion in order to calculate a range of NO_x emissions in kilograms for that working year. The total emission from explosives was then compared to total emissions for diesel equipment at the mine.

Results and analysis

Tables 3 and 4 show the size, number of operating hours per year, fuel consumption per year and NO_x emission per year for mining equipment: drills, bulldozers, hydraulic excavator, graders, haul trucks, water trucks and front-end loaders.

Figures 1 and 2 show a total number of operating hours and fuel consumption per year, respectively, for all mining equipment. Annual fuel consumption of the equipment is more than 20 million L (5.3 million gal), and haul trucks consume around 57% of all fuel in the mine, followed by bulldozers and front-end loaders, with 17% and 15%, respectively.

Minimum product factors for ANFO and emulsion were found to be 2 and 2.7 L/kg (6.4 and 8.6 lbs/st), respectively, and maximum values of 36.5 and 6.2 L/kg (122.9 and 24.6 lbs/st), respectively (Table 5). These values were multiplied by the total kg of explosive for the year to produce a minimum NO_x emission of 86 t (95 st) and a maximum emission of 827 t (914 st). This is a huge range due to the complexity of factors that contribute to the production of NO_x from blasting. The upper limit is based on very heavy confinement of galvanized sheet metal for ANFO and long exposure to water for emulsion. Confinement of galvanized sheet metal would not be found on a mine site and emulsion should not be exposed to water for prolonged periods of time, but this maximum value gives an indication of the possible levels of NO_x that can be produced from blasting. Using the EPA standard product factor of 5.7 L/kg (17 lbs/st) for ANFO gives a total NO_x emission of 195 t (215 st).

An annual NO_x emission for mining equipment and blasting is shown in Fig. 3. The total annual NO_x emission of mining equipment is about 682 t (751 st). It can be noted

Table 3

Number of operating hours, fuel consumption and NO_x emission per year for haul trucks and drills.

Equipment ID	Size	Number of operating hours (hours/year)	Fuel consumption (L/year)	NO_x emission (t/year)
Haul truck #1	81 T	191	9,834	0.34
Haul truck #2	81 T	2,234	103,213	3.54
Haul truck #3	81 T	2,210	104,712	3.59
Haul truck #4	181 T	3,789	300,077	10.29
Haul truck #5	181 T	3,847	227,140	7.79
Haul truck #6	181 T	4,412	267,882	9.18
Haul truck #7	181 T	5,190	325,750	11.17
Haul truck #8	181 T	5,248	288,017	9.87
Haul truck #9	181 T	4,860	343,382	11.77
Haul truck #10	181 T	3,562	259,978	8.91
Haul truck #11	181 T	3,742	331,636	11.37
Haul truck #12	181 T	4,834	403,714	13.84
Haul truck #13	181 T	4,640	379,775	13.02
Haul truck #14	181 T	4,884	466,060	15.98
Haul truck #15	181 T	4,004	412,500	14.14
Haul truck #16	181 T	3,683	323,834	11.10
Haul truck #17	217 T	5,009	535,166	18.35
Haul truck #18	217 T	4,156	472,654	16.20
Haul truck #19	217 T	4,661	498,115	17.08
Haul truck #20	217 T	4,701	500,318	17.15
Haul truck #21	217 T	4,662	489,953	16.80
Haul truck #22	217 T	4,972	493,534	16.92
Haul truck #23	217 T	4,908	483,881	16.59
Haul truck #24	217 T	4,963	511,049	17.52
Haul truck #25	217 T	4,903	530,828	18.20
Haul truck #26	217 T	4,839	507,964	17.41
Haul truck #27	217 T	4,807	521,118	17.87
Haul truck #28	217 T	4,596	457,849	15.70
Haul truck #29	181 T	2,703	228,616	7.84
Haul truck #30	181 T	2,720	251,983	8.64
Haul truck #31	181 T	2,903	221,431	7.59
Haul truck #32	181 T	2,275	176,707	6.06
Drill #1	200 mm	2,303	125,956	2.93
Drill #2	200 mm	1,900	111,586	2.60
Drill #3	200 mm	3,091	168,504	3.93
Drill #4	229 mm	3,209	216,957	5.06
Drill #5	270 mm	2,079	173,273	4.04
Drill #6	229 mm	3,022	278,727	6.49
Drill #7	229 mm	2,953	279,322	6.51
Drill #8	270 mm	1,959	266,781	6.22

that haul trucks generated the largest amount of NO_x, i.e., 392 t (431.9 st), which is more than all other equipment combined. Dividing cumulative annual NO_x emission of the equipment by total annual fuel consumption shows that an average of 0.034 kg of NO_x has been emitted per each liter of diesel fuel used by the equipment (0.283 lb/gal). The NO_x emission from blasting is 195 t (215 st).

Figure 4 shows the pictorial representation of the contribution of specific mining equipment and blasting in a cumulative annual NO_x emission in the mine. It can be seen that haul trucks are represented by 44.69%, followed by blasting (22.25%), front-end loaders (13.37%), bulldozers (13.29%), drills (4.31%), graders (1.03%), water trucks (0.98%) and hydraulic shovel (0.07%).

There are various factors that affect NO_x emission of mining equipment, such as the age of equipment, engine power, engine tier level, load factor, etc. This emission can increase with time for several reasons, such as poor maintenance practices and engine wear (EPA, 2010).

Many equipment manufacturers have worked to incorporate improved emissions technology into their equipment during the past years. Tier 4i is the current EPA standard for off-highway diesel engines in the United States. It requires engines to reduce emission of particulate matter (PM) and nitrogen dioxides. The next stage of the EPA standard (Tier 4 final), which is anticipated to come into effect in 2014-2015, will require that NO_x and PM exhaust emissions must be cut by 90% compared to the Tier 3 level (Ueno, 2010). Details on EPA standard levels can be found in EPA (2010).

Various improvements may be conducted to reduce exhaust emissions from mining equipment. Reducing engine idling may be an effective strategy to reduce exhaust emissions (Smith et al., 2007). Equipment operators may help reduce the air pollutants in working environments by turning off equipment engines when they are not in use. In planning day-to-day activities, mines may save on fuel costs by taking steps to maximize equipment use and minimize idling time (EPA, 2002). Using cleaner fuel may also reduce exhaust emissions. Burning cleaner diesel fuel, or alternative fuels such as biodiesel, may help reduce exhaust emissions. Some examples of cleaner fuels include low-sulfur diesel, ultra-low-sulfur diesel, biodiesel and emulsified diesel. Each type of cleaner fuel reduces a particular kind of pollutants. The first two types can be used to reduce particulate matter. Biodiesels also have an effect on particulate matter reduction. However, NO_x emissions increase with the concentration of biodiesel in the fuel (EPA, 2013). Emulsified diesel reduces fine particles and NO_x emissions. It is a blended mixture

Table 4

Number of operating hours, fuel consumption and NO_x emission per year for wheel loaders, graders, bulldozers, water trucks and hydraulic shovel.

Equipment i.d.	Size	Number of operating hours (hours/year)	Fuel consumption (L/year)	NO_x emission (t/year)
Wheel loader #1	11.5 m^3	4,577	164,143	6.32
Wheel loader #2	11.5 m^3	2,501	156,599	6.03
Wheel loader #3	11.5 m^3	3,839	298,116	11.48
Wheel loader #4	11.5 m^3	5,087	492,141	18.94
Wheel loader #5	11.5 m^3	5,274	438,665	16.89
Wheel loader #6	11.5 m^3	3,075	252,805	9.73
Wheel loader #7	13 m^3	3,319	320,825	12.35
Wheel loader #8	13 m^3	4,475	347,716	13.38
Wheel loader #9	13 m^3	5,362	574,682	22.12
Grader #1	362 kW	3,818	64,821	1.97
Grader #2	362 kW	4,678	132,137	4.02
Grader #3	362 kW	4,219	101,139	3.08
Bulldozer #1	433 kW	4,421	199,714	6.82
Bulldozer #2	433 kW	2,602	134,287	4.58
Bulldozer #3	433 kW	2,963	175,310	5.99
Bulldozer #4	433 kW	4,710	269,926	9.22
Bulldozer #5	433 kW	2,955	158,896	5.42
Bulldozer #6	433 kW	4,404	260,391	8.89
Bulldozer #7	433 kW	5,364	214,016	7.31
Bulldozer #8	433 kW	4,942	202,614	6.92
Bulldozer #9	433 kW	5,426	217,203	7.42
Bulldozer #10	433 kW	5,277	232,928	7.95
Bulldozer #11	634 kW	5,681	453,080	15.47
Bulldozer #12	634 kW	4,282	307,864	10.51
Bulldozer #13	634 kW	5,832	470,564	16.07
Bulldozer #14	362 kW	5,141	116,477	3.98
Hydraulic shovel #1	1.8 m^3	1,239	14,494	0.59
Water truck #1	113,562 L	2,133	163,242	5.60
Water truck #2	113,562 L	1,445	87,572	3.00

of diesel fuel, water and other additives. Emulsified diesel can be used in any diesel engines, but the addition of water reduces the energy content of the fuel, so some reduction in power and fuel economy can be expected. Emulsified diesel can reduce emissions of smog-causing NO_x between 10 and 20% and fine particles between 50 and 60% (EPA, 2006).

Conclusions

The objective of this research was to determine NO_x emission of mining equipment and blasting agents for a specific surface coal mining operation in West Virginia. An emission factors method was used to determine the NO_x emission for mining equipment. The data for eight drills, 14 bulldozers, a hydraulic shovel, three graders, 32 haul trucks and nine front-end loaders, as well as two water trucks, were considered. Trucks in the mine achieved the largest annual number of working hours and annual fuel consumption, followed by bulldozers and front-end loaders. Results showed that 877 t (966 st) of NO_x per year was emitted in the mine. Haul trucks, blasting, front-end loaders and bulldozers contributed to the total NO_x emissions by 44.69%, 22.25%, 13.37% and 13.29%, respectively. Graders, drills, water trucks and the hydraulic

Figure 1

Total number of operating hours of the mining equipment.

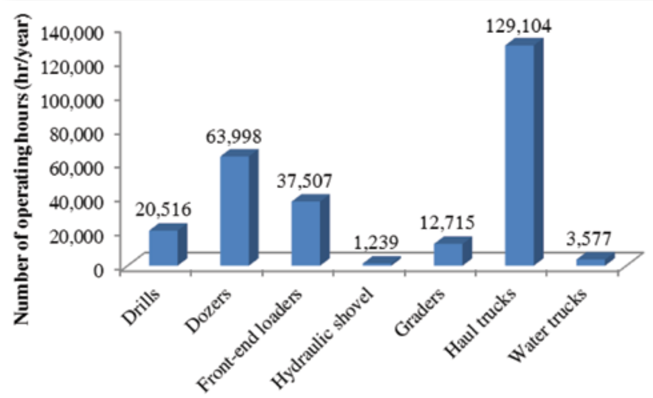


Figure 2

Annual fuel consumption of the mining equipment.

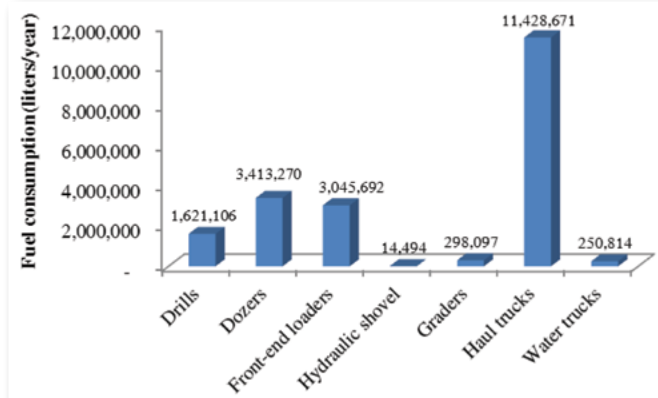


Table 5

Range of NO_x emissions from explosives.

	Minimum		Maximum		EPA
	ANFO	Emulsion	ANFO	Emulsion	
Product factor (L/kg)	2	2.7	36.5	6.2	5.7
Kg NO_x	86,320		829,526		195,071
Tons NO_x	86		827		195*

* Value based on the total ANFO and emulsion tons, since no standard product factor for emulsion is known.

Figure 3

Annual NO_x emission for mining equipment and blasting.

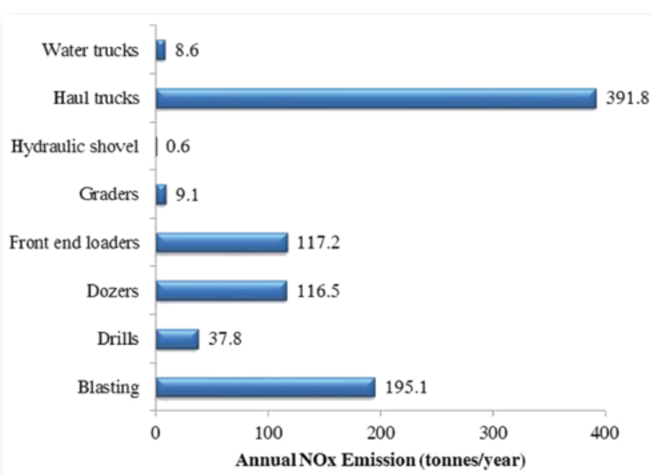
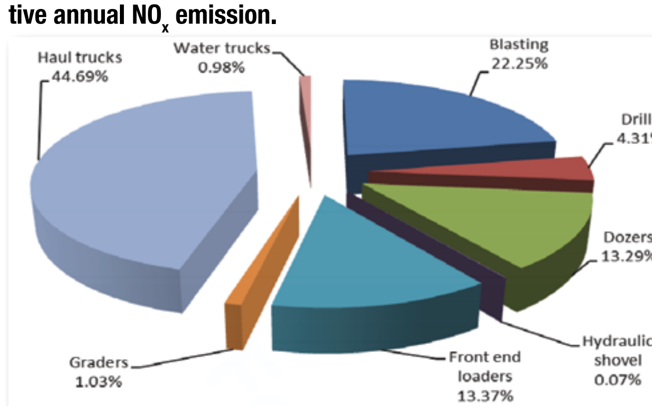


Figure 4

Contribution of mining equipment and blasting in a cumulative annual NO_x emission.



shovel contributed 6.4% of total NO_x emissions.

An extensive review of literature into NO_x emissions from explosives demonstrated that there is a complex set of factors contributing to increased levels of NO_x produced from blasting. These include, but are not limited to, under fueling ANFO, excessive confinement and contamination from water or drill cuttings. It has also been established that emissions will differ for each blast design and rock type, making predicting or calculating precise NO_x emissions difficult. A range of NO_x emissions for a year at a mine in West Virginia was calculated to be from 86-827 t (95-914 st), based on product factors established from published literature for ANFO and emulsion. The high end of the range is greater than emissions for all diesel equipment used at the mine; however, the value is based on a worst case scenario for each blast throughout the year. A standard product factor is available for ANFO of 5.8 L/kg (17 lbs/st), but it has not taken into account contamination or confinement and is based solely on chemical composition. Despite this, when used to calculate NO_x emissions for the mine, the result of 195 t (215 st) is in the middle of the range calculated from the literature, making it a more feasible estimation than either the minimum or maximum values. There is less research into emulsion and no standard product factor for NO_x is available, even though it is one of the most frequently used explosive types. It has been established that confinement and contamination from drill cuttings and water have a significant impact on the volume of NO_x produced from a blast; however, little is known about which explosives react with specific ground conditions and contamination from them. Matching explosives product to ground conditions could be crucial in controlling NO_x emissions. Further work is needed on NO_x emissions from explosives with respect to contamination from drill cuttings and varying rock types. ■

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