NITROGEN INFLATION OF EM TIRES

1. Introduction

Air is the traditional inflation medium for most tires, including earthmover (EM) tires. Nitrogen is an alternative to air inflation. Because nitrogen is an inert gas it does not support combustion. For this reason nitrogen is used extensively in commercial aviation applications – to minimize the risk of tire explosions.

Nitrogen inflation was first implemented in the mining industry in the 1970's (mainly to reduce the likelihood of tire explosions) and its use has become more widespread over time. However air remains overwhelmingly the main inflation medium for mines worldwide. Notwithstanding this, nitrogen inflation has been adopted by a significant proportion of mines in some geographic locations, eg. South America.

There are three main processes for obtaining nitrogen gas on a mine site:

1. Nitrogen gas cylinders (that contain nitrogen gas at 2,100 psi)
2. A liquid nitrogen storage tank with evaporators to convert the liquid nitrogen into nitrogen gas
3. An on-site nitrogen generation plant using the Pressure Swing Absorption (PSA) process or the Membrane Separation process[1].

Gas cylinders and bulk liquid nitrogen are relatively well known mediums for EM tire inflation. The onsite generation systems, PSA and Membrane Separation, are less commonly used, although Membrane Separation is becoming more popular.

Some important elements associated with the use of nitrogen in tires are generally misunderstood, and there remain several overstated (sometimes false) claims about the benefits of nitrogen.

This article examines the benefits and costs of nitrogen inflation of EM tires, and misconceptions concerning its use. It also presents recommendations for the evaluation and use of nitrogen inflation on a mine site.

2. Benefits of the use of nitrogen

There are five main benefits claimed for using nitrogen to inflate tires:

1. elimination of tire explosion (this is generally the principal reason for the implementation of nitrogen inflation)
2. reduced rim corrosion
3. improved tire pressure retention
4. cooler running/lower pressure buildup during operation
5. reduced aging of tire inner liner and carcass.

2.1 Elimination of tire explosion

The principal reason for implementing nitrogen inflation is usually to minimize the risk of a tire explosion. Tire explosions are not common, but they are catastrophic

[1] The Brannick Membrane system, promoted by Nitralife (South Africa) is an example of this process.

events that have caused fatalities to mining and maintenance personnel, and extensive damage to mining equipment and facilities.

The main causes for tire explosions are:

1. Machine contacting high-voltage overhead power lines
2. Lightning strike to machine
3. Application of heat to wheels (usually through oxyacetylene treatment)
4. Overheating brakes
5. Machine/tire fire.

In the above cases a heat source generally causes pyrolysis of a section of the tire's inner liner producing flammable gases. An explosion will occur if all of the following criteria are met:

1. There is at least 5.5% oxygen content by volume in the inflation chamber of the tire, plus
2. sufficient flammable gas is produced to form an explosion concentration, plus
3. there is enough energy (generally heat) to produce auto-ignition of the gas mixture.

Nitrogen will not prevent the formation of flammable gases by pyrolysis, but if the nitrogen has been properly applied to the tire (and the tire inflation chamber has not subsequently had an ingress of air for whatever reason), then there should be insufficient oxygen to form a combustible gas mixture.

In addition to the well documented causes of tire explosions listed above, a further explosion mechanism exists that requires no more heat than that produced during the normal operation of a tire. There is a known case of a tire exploding due to the diffusion of methanol gas from packing wood that had been inadvertently placed in an EM tire and had not removed when the tire was mounted onto a rim. The normal operating pressure and temperature of this tire was sufficient to auto-initiate the explosive gas mixture that had formed through methanol diffusion. Again, in this case, nitrogen would not have prevented the formation of flammable gases through the diffusion process; however its proper application would have prevented the explosion because there would have been insufficient oxygen to form a combustible gas mixture.

Nitrogen inflation, properly applied, will significantly reduce the risk of tire explosion but it will not eliminate it. Nitrogen inflation, incorrectly applied, may not reduce the risk of tire explosion at all[2].

2.1.1 Difference between explosion and impact

It is important to differentiate between a tire explosion and a tire impact. A tire explosion results from the initiation of an explosive gas mixture within the air chamber of a tire. The explosive pressure is generally in the order of 1,000 psi. Fatalities and major equipment or facility damage are commonplace with tire explosions. Tire explosions are very rare occurrences.

[2] These two issues are examined in more detail later in this article.

Tire impacts (also termed blowouts or bursts) are generally caused by rock damage during operation. In some events, a tire whose structural integrity has been weakened by rock, heat or mechanical damage, has burst either during operation or (in rare circumstances) while the tire has been at rest. Impacts or bursts typically involve an inflation pressure of between 100 and 140 psi, considerably lower than that associated with a tire explosion. While the risk of injury (even death) or damage remains high with a tire burst, it is not of the same order as with a tire explosion. Tire impacts are common occurrences.

While nitrogen, properly used, will minimize the likelihood of a tire explosion, its use will have no effect on the risk of a tire impact or burst.

2.2 Reduced rim corrosion

Nitrogen inflation will reduce rim corrosion (but not eliminate it); the benefit may vary greatly by mine site depending on environmental and compressor outlet air quality (mainly in relation to moisture content). One South American mine using nitrogen still had a major problem with valve core blockages from rust.
Many mines also use tire sealant, the best of which have excellent anti-corrosive properties.

The benefit of nitrogen in reducing rim corrosion will vary by operation; it may be considerable on some mine sites and insignificant on others.

2.2.1 Airline moisture content

Moisture in the compressed air system is a major problem on some mine sites, and can greatly increase the severity of rim corrosion. Nitrogen inflation would generally be of great benefit in this circumstance as it contains no moisture.

2.3 Improved pressure retention

Nitrogen suppliers claim that nitrogen permeates more slowly than air through rubber because it has a larger molecule size[3]. Air is composed of 78% nitrogen, 21% oxygen and 1% other gases, and hence any variation in permeability between nitrogen and air would have to be factored down by approximately four-fifths.

Pressure loss from tires depends on much more than just permeation of the inflation gas through the tire itself. Leaking O-rings – due to either defective or incorrectly installed O-rings, or a worn rim gutter section – are a common cause of tire pressure loss, totally unrelated to the inflation medium.

Anecdotal evidence from mine sites using nitrogen ranges from a dramatic improvement in tire pressure control (eg. Antamina copper mine in Peru) to virtually no discernable variation (eg. Collahuasi copper mine in Chile) between the use of nitrogen and air.

The benefit of nitrogen in improving tire pressure retention will almost certainly vary by operation; it may be considerable on some mine sites and insignificant on others.

[3] Although nitrogen (atomic number of 7) is lower than oxygen (atomic number of 8) in the Periodic Table of Elements, it forms a larger molecule than oxygen – 0.31 compared with 0.29 nanometers.

2.4 Cooler running tires/Lower pressure buildup

There is no theoretical basis for the claim that tires will run cooler with nitrogen. This is borne out be examination of the General Gas Equation (Pressure x Volume / Temperature = constant). The volume of a tire's air chamber does not change measurably during tire operation. Temperature buildup is generated by tire flex during operation. Pressure buildup is determined by the buildup in tire temperature. Tire temperature buildup, and subsequent inflation pressure increase, is a function of the inflation pressure setting, tire loading and machine speed. It is not determined by the type of gas used for inflation of the tire.

In the mid-1970's Otraco conducted a detailed test program at the BHP-Billiton Newman mine site comparing the influence of air and nitrogen inflation on haultruck tire operating temperature. There was no discernable difference between the two inflation mediums.

The claim that nitrogen inflation results in cooler operating tires is false.

2.5 Reduced aging of tire liner and carcass

The use of nitrogen may reduce oxidation induced aging of rubber in the tire's inner liner or carcass. However the amount of aging is minimal and insignificant in terms of overall tire structural or inflation chamber integrity.

The level of aging reduction provides no benefit in terms of extended tire life or improved safety.

3. Disadvantages of nitrogen

There are potential safety risks and additional costs associated with the use of nitrogen.

3.1 Safety hazard with gas cylinders

The handling of gas cylinders with 2,100 psi pressure can create its own safety hazards, particularly if equipment is faulty or used incorrectly (eg. without a pressure regulator). Transporting high pressure cylinders around the pit is fraught with potential hazards. In some countries there have also been problems with the incorrect gas being supplied in nitrogen bottles[4] – rare but potentially very dangerous. These risks would be significantly reduced by using the liquid nitrogen or onsite generation methods; however both of these methods require substantial on-site facilities and do not allow for mobile inflation units in the mine itself (gas bottles are still needed if a mobile delivery system is required).

Other precautions that are required with nitrogen inflation are associated with its ability to asphyxiate people in an enclosed space. For example a tire fitter should never climb into or put his head into a tire that has been inflated with nitrogen, as he could lose consciousness and suffocate.

[4] A mine site in Indonesia was supplied with a nitrogen gas bottle filled with oxygen.

3.2 Cost/Logistics

Relative capital and operating costs for the various nitrogen inflation systems are discussed below.

3.2.1 Setup and ongoing costs

Relative capital and operating costs for the four main mine site supply processes (gas bottles, liquid storage tank, onsite PSA plant generation and onsite Membrane Separation) are as follows:

A. Capital cost
- Lowest cost: Gas bottles
- Intermediate cost: Liquid storage tank; Membrane Separation process
- Highest cost: Onsite PSA plant generation

B. Operating/supply cost
- Lowest cost: Membrane Separation process, Onsite PSA plant generation; Liquid storage tank
- Highest cost: Gas bottles

The cost of transporting nitrogen to the mine site (in the case of gas bottles and liquid nitrogen) is a critical element of the economic evaluation. For a large mine site, close to a nitrogen supplier, a liquid storage tank facility would generally be the most economical option. For a very remote mine site, onsite nitrogen generation (PSA or Membrane Separation) would probably be the only practical option, although there could be significant maintenance downtime if the PSA system was utilized; hence a backup system (bottles or liquid storage tank) may be necessary.

The Membrane Separation process tends to have relatively low volume output compared with the other systems. This could impact on tire inflation time and hence haultruck tire change downtime. Nitrogen volume can be increased in a membrane generator, but at the expense of nitrogen purity.

Gas bottles may be the preferred option for a very small fleet, where the capital cost of the two other systems could not be justified (however gas bottles are the least preferable in terms of handling safety).

In 1996 a small fleet mine in Australia, using nitrogen gas bottles, discontinued its nitrogen inflation program after seven years of use. They concluded that the claimed benefits could not justify the additional expense.

3.2.2 Control of inflation outlets

For any mine site planning to adopt nitrogen inflation it would be essential that all facilities used to inflate tires, eg. tire workshop, tire service truck, refuelling stations, and outlets in haultruck and auxiliary equipment workshops were converted to nitrogen delivery.

Procedures would also need to be implemented to ensure that compressed air would never be introduced into nitrogen inflated tires (eliminating the explosion risk reduction benefit).

3.3 Complacency

The use of nitrogen for the purpose of preventing tire explosions could engender an atmosphere of complacency in the maintenance and operation of earthmover tires, possibly increasing the risk of explosion in some cases. The main potential for complacency is in relation to haultruck or tire fires and the application of heat to rims fitted with tires. This issue is examined in more detail below.

4. Nitrogen inflated tires can explode

Prevention of an explosion cannot be guaranteed through nitrogen inflation of tires. Prior to its closure, the Bougainville Copper Mine in Papua New Guinea had a tire explosion resulting in a fatality even though it was using nitrogen inflation.

A professional risk analysis on nitrogen fill (undertaken following an earthmover tire explosion in Australia) recommended against the use of nitrogen inflation because it would not prevent tire explosions totally. The study suggested that the elimination of conditions that could cause an explosion was a better method to pursue.

4.1 Oxygen content

There are several potential causes for tire explosions on mine sites where nitrogen inflation is being used. All are related to the oxygen content of a tire's inflation chamber being insufficiently low (less than 5.5% by volume) to eliminate the risk of an explosion. They are:

1. Insufficient purging of atmospheric air from a tire during the initial mounting/inflation process.
2. Adding air (rather than nitrogen) to a nitrogen inflated tire that required additional pressure.
3. A nitrogen inflated tire that has run-flat during service.
4. Application of heat to a nitrogen inflated tire that has been deflated and one of its two seating beads has come loose from the rim.

4.1.1 Purging of air

If nitrogen inflation is incorrectly carried out, then the percentage of oxygen within the final inflation mixture may not be less than 5.5% by volume[5]. Inflation of tires with nitrogen requires one of two procedures to ensure that the level of oxygen that exists (due to normal air at atmospheric pressure) in the tires inflation chamber prior to and during fitment of the tire to a rim is reduced to less than 5.5% during the tire inflation process.

1. Either a double inflation process (inflate with nitrogen, deflate to nearly flat, inflate with nitrogen again)
2. or a single inflation process (over-inflate with nitrogen initially, eg. to 140 psi, then deflate to the normal pressure setting, eg. 110 psi).

[5] The need to reduce the level of oxygen to less than 5.5% by volume is neither well known nor understood in the industry.

If these steps are carried out incorrectly, or if pressure measuring equipment is faulty, then tires that are believed to be ‘explosion-proof’ may in fact not be.

4.1.2 Adding air

If a nitrogen inflated tire needs to be re-inflated to its correct pressure setting (eg. due to normal pressure loss in operation), then it is essential that pure nitrogen is added. Addition of air, rather than nitrogen (either on purpose or inadvertently), is most likely if the tire is re-inflated in a location outside the tire workshop, eg. in the field or in a general maintenance workshop.

4.1.3 Run-flat tires

Rear tires on haultrucks routinely run-flat (eg. due to a rock penetration) and are often not detected by the driver for a considerable period of time. Prolonged running-flat of a tire leads to significant heat buildup within the tire carcass and can result in the tire catching fire. Because the tire has run flat, typically with one or both of the tire beads having come loose from the rim, the percentage of oxygen will be close to normal atmospheric conditions (21% by volume) and if the tire fire were to lead to the production of inflammable gases, through pyrolysis, in the tire’s inflation chamber, then a tire explosion could occur.

4.1.4 Deflated tires

A common cause of tire explosions is the application of heat (eg. oxy-acetylene heating or cutting) to a rim that has a tire fitted to it. An explosion is possible irrespective of whether the tire is inflated or not[6]. If a nitrogen inflated tire is deflated prior to the addition of heat to the rim, and if one of its beads has come loose from the rim, then the percentage of oxygen will be close to normal atmospheric conditions (21% by volume). If the heating results in the production of inflammable gases, through pyrolysis, then a tire explosion could occur[7].

Heat should never be applied to a rim that has a tire mounted on it, irrespective of whether the tire is inflated with air or nitrogen, or whether the tire has been deflated or not.

4.2 Oxygen measurement gauge

Test units are available to detect the level of oxygen in a gas mixture (the oxygen level must generally be less than 5.5% by volume to eliminate the risk of an explosion).

All mine sites using nitrogen should have one of these test units, and its use should be incorporated into the mine’s tire checking procedures.

[6] There is a common and incorrect perception in the mining industry that deflating a tire, which is mounted to a rim to which heat will be applied, will eliminate the risk of a tire explosion.
[7] If a properly inflated nitrogen filled tire is not deflated prior to heating the rim, then it is unlikely that a tire explosion would occur during the heating process, even though inflammable gases might be created in the inflation chamber through pyrolysis due to the heating process. But then you would have created a potential bomb, that would only require the inadvertent addition of air at some later stage, and a hot spot, to create the conditions for an explosion.

5. Conclusions

Whether or not a mine should implement nitrogen inflation for its EM tires, and if so which system should be employed, will depend on the following main factors.

1. What are the risks of a tire explosion on site?
    a. Is the mine prone to lightning storms?
    b. Are there high voltage overhead power lines situated in areas vulnerable to haultrucks?
    c. Is the truck fleet prone to serious brake overheating or truck fires?

2. Are these risks acceptable?
    a. Even if the risk of tire explosion is low, is any risk acceptable?

3. Is it likely that rim corrosion can be significantly reduced?
    a. Is it likely that cost saving generated by reduced rim corrosion with nitrogen use would more than offset the additional cost of using nitrogen?
    b. Are there safety considerations with rim corrosion that would justify the implementation of nitrogen?
    c. Could corrosion be controlled by a means more economical than nitrogen, eg. sealant?

4. Is it likely that tire pressure control can be significantly improved?
    a. What is the likely increase in tire life (and associated reduction in the annual tire bill) due to improved pressure maintenance?
    b. Can equipment utilization be improved through better tire pressure control?

5. Can compliance of nitrogen inflation procedures be assured?
    a. If reduction of explosion risk is the prime reason for considering the use of nitrogen, can proper inflation and re-inflation procedures be implemented and compliance assured?

6. What is the EM equipment fleet size?
    a. If a decision is made to use nitrogen, the most economical solution for a small mine may be nitrogen bottles (although handling safety could be a consideration), while medium to large fleets would favor liquid nitrogen storage or onsite generation.

7. How close are nitrogen supply facilities?
    a. A nearby supply facility would favor gas bottles or liquid storage; a remote facility would favor onsite generation of nitrogen.

6. Recommendations for the evaluation or implementation of nitrogen inflation

If it seems that the potential safety and/or cost saving benefits of nitrogen inflation are sufficient to justify its use, we recommend that a two step plan be adopted:

1. Evaluation and final justification
2. Final implementation.

6.1 Evaluation and final justification stage

Conduct a limited trial first comparing the performance of nitrogen inflated tires on test trucks (or other relevant equipment) against air inflated tires on control trucks – select an equivalent number of test and control trucks (six trucks is the suggested minimum for each); trucks should be of similar specification, application and rim type and condition.

The evaluation should preferably be conducted by having the nitrogen supplier inflate the test tires from nitrogen bottles. This minimizes the evaluation costs for the mine site (compared with pre-installation of a liquid tank or onsite generation system), while minimizing exposure of mine company employees to the handling risks associated with nitrogen bottles.

Monitor and compare the following maintenance and operation parameters:

1. Tire inflation and re-inflation (only valid if the nitrogen delivery method used for the test program is the same method that will be used if final implementation of nitrogen fill is adopted)
    a. Measure and compare time to inflate and re-inflate test and control tires.
    b. Determine if there are any operational or safety issues in the inflation or re-inflation processes.

2. Tire pressure retention
    a. Measure the average frequency and magnitude of tire pressure loss between test and control trucks.
    b. Measure the average downtime associated with re-inflation of test truck and control truck tires.

3. Rim corrosion
    a. Fit at least two new rims, sandblasted to remove all paint from the air chamber surface, to each of the test and control fleets (this test could be extended to include sealant and non-sealant treated tire assemblies).
    b. The rims should be examined (requiring the removal of the tires) and compared after a three month operating period.

6.2 Final implementation stage

If the evaluation provides final justification for the use of nitrogen, install the delivery system of choice (gas bottles, liquid storage tank or onsite generation).

Ensure that the facility size will be sufficient to handle the existing and future equipment fleet on site (taking into account not only truck numbers, but tire sizes as well). Alternatively, ensure that any future upgrade of the nitrogen delivery system can be done economically.

6.3 Additional points

Even if the nitrogen supplier is prepared to install the facilities at no charge (eg. a liquid storage tank facility), we recommend an initial evaluation program comparing test and control trucks, rather than immediately converting the complete fleet to nitrogen inflation. This is the only way that quantifiable benefits (or otherwise) of nitrogen use can be obtained.

7. Critical issues

Tire explosions can still occur, even though nitrogen inflation is used. Tire maintenance and operations personnel must understand the importance of maintaining an oxygen level of less than 5.5% in the tire inflation chamber, and that any action that compromises this condition can result in a tire explosion.

- It is crucial that adequate inflation procedures are adopted and maintained to ensure that oxygen level is kept at less than 5.5% by volume in order to avoid one of the pre-conditions for a tire explosion.

- Regular testing of the oxygen level in the tire inflation chamber using an appropriate test device should be incorporated into the site tire maintenance and operating procedures.