Remote monitoring of bulk explosive storage facilities

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Ammonium nitrate is the cheapest and safest source of readily deliverable oxygen for blasting applications. The extensive use of ammonium nitrate in Ammonium Nitrate Fuel Oil (ANFO) and water-based commercial explosives have largely displaced the nitro-glycerine-based dynamites. Ammonium nitrate industrial explosives are low cost, safe, versatile in performance and application, and have better storage stability than dynamites.

A large number of formulations are available for almost all purposes. The use of ammonium nitrate mixed with a fuel was proposed as a commercial explosive as early as 1867. It was only with the development of anticaking agents in the 1950s that ANFO became practically useful for rock blasting. Ammonium Nitrate Fuel Oil compositions (ANFOs) consist of 94% ammonium nitrate prills coated with an anticaking agent and 6% absorbed fuel oil [1]. ANFOs are relatively insensitive to detonation and usually require a high explosive booster to initiate detonation.

The sensitivity of ANFOs to initiation is affected by its composition, physical characteristics, and environment. Decreasing the particle size and density of ammonium nitrate or increasing its porosity increases the sensitivity of the mix to initiation. Maximum sensitivity occurs at oil concentrations of around 2%–4%. The presence of water decreases the sensitivity. The detonation velocity increases as the oil content increases to a maximum at around 6% oil. Maximum velocity is about 4300 m/s for large diameter ANFO charges. Confinement also increases the detonation velocity. The addition of metallic fuels, such as aluminium or ferrosilicon, increases the energy content. Stabilizers and inhibitors may be added and the fuel oil may be dyed to identify specific compositions [1]. The ANFOs may be mixed on site simply by adding oil to a bag of prills. More effectively, they can be prepared in onsite trucks equipped for the purpose and then augered into boreholes.

Historically a number of miners have been killed or injured by explosives and blasting agents. Most explosives-related injuries and fatalities in surface mines occur when workers are struck by rock, either because they were too close to the blast or rock was thrown much farther than expected. The second leading cause was blasts that shoot prematurely. In underground mines, most explosive-related fatalities were caused by miners being too close to the blast, followed by explosive fumes poisoning, misfires, and premature blasts. Misfires lead to injuries and fatalities as miners try to shoot explosives that failed to detonate in the original blast.

Premature blasts occur without warning while blasters are near the explosive-loaded boreholes; the explosive may be initiated by lightning, the impact of explosives being dropped down a dry borehole, or careless handling of the initiating system (blasting caps) [2].

Ammonium nitrate will not explode due to the friction and impact found in normal handling, but it can be detonated under heat and confinement or severe shock. Ammonium nitrate is classified as an explosive and assigned to Class 1 of the UN classification system. Consequently the transportation, storage and handling of ammonium nitrate falls under the Explosives Act of 2003. In order to avoid hazards and minimise the potential consequences of an incident, the basic principles that should be adopted are the same as for all other explosives operations. This is 'Always expose the minimum number of personnel to the minimum amount of explosives, for the minimum period of time' [3].

The practical implementation of these principles requires that the quantities of explosives and raw materials must always be kept as low as practical. There should also be as few people as possible involved the process. Ideally there should either be only one operation per location one operation at a time.

During handling the amount of energy going in must be kept to a minimum. Automation and remote monitoring can be used to address a number of these requirements.

ANFO – Ammonium Nitrate Fuel Oil
CIE – Chief Inspector of Explosives
PPAN – Porous Prilled Ammonium Nitrate
SIL – Safety Integrity Level

Abbreviations/Acronyms

Bulk explosives storage safety monitoring and control

A discussion on the deployment of safety control systems in bulk explosives delivery trucks, underground controllers and other safety systems is described in [4]. The loading of bulk explosives into drill holes for production blasting is performed by a bulk explosive truck which has a mobile manufacturing plant. During a typical mining cycle these trucks may need to be reloaded one or more times with bulk products. This necessitates the placement of bulk storage silos at a convenient location on the mine. The size of the storage silos is a trade-off between the daily consumption and time to refill from road tankers. Road transportation of bulk explosives by tanker is costly and subject to additional hazards. The following materials are stored on-site for the manufacture of blasting agents:

- **Porous Prilled Ammonium Nitrate** (PPAN): Low sensitivity to shock, friction or impact, is comparatively safe to handle [5]
- **Ammonium Nitrate based Emulsion:** Low sensitivity to shock, friction or impact, is comparatively safe to handle and use. Non explosive until the emulsion has been gassed, or mixed with PPAN [6]
- **Diesel Fuel:** Even though its flash point is greater than 60°C, catches fire quickly and hence has to be kept away from AN and AN/FO in storage. Under the right conditions diesel vapour / air mixtures in storage tanks are flammable or explosive

'Always expose the minimum number of personnel to the minimum amount of explosives, for the minimum period of time'.

The products in the bulk storage facility contain material that have not been mixed and are thus relatively insensitive to detonation. Nevertheless products that contain ammonium nitrate are still able to detonate under conditions of high pressure, temperature and confinement. Analysis of possible hazard locations and history of accidents in the last 10 years has shown that pumps are equipment with highest risk [7]. Several situations can occur during the pumping operation which can put extraordinary heat, friction, and compression on the product leading to explosions. Hazardous situations which can arise in most water-based emulsion explosive pumping operations include:

- Blocked inlets
- No feed from the storage tank
- Blocked outlet
- Worn out pump rotor or stator
- Foreign object stuck inside the pump
- Pumping against a deadhead

These hazards can be detected by the measurement of pressure, flow, level and temperature. An electronic controller is commonly used to monitor and control the loading and unloading processes. The following conditions are monitored and will trip the transfer process and generate an alarm:

- Temperature above or below pre-set safety thresholds
- Pressure above or below pre-set safety thresholds
- Flow above or below pre-set safety thresholds

These safety monitoring and control units are linked to a remote control room where the alarm and trip information is recorded and relayed to supervisors.

The silo level is also monitored to determine the site production and when the product need to be replenished. The level of the bulk material in the silos is manually measured or monitored using ultrasonic level probes. These are mounted at the top of the silo with the sensor element focused towards the base of the silo.

A length of cable is routed from the top of the silo to the base where the level sensor control unit and display is located. 4-20 mA process loops are typically is used to connect this to the silo monitoring system. The equipment used for the bulk silo safety monitoring and control is not required to be SIL certified at present.

Case study:
Non-intrusive level monitoring

The use of an ultrasonic level sensor in this application has a number of operating and installation hazards. Although the ultrasonic level sensor uses a non-contact principle, the sensor needs to be positioned inside the silo.

This will be in contact with the potentially hazardous dust or vapours present inside the silo. Installation and repairs are also hazardous as they require working at height. Permits and special safety gear are required when installing or repairing on this equipment. Field experience has proven that the sensors are prone to failure in high lightning areas which requires frequent repair.

Various alternative level sensing technologies were considered which could reduce or eliminate the hazards described. An indirect level measurement technique is being evaluated where the silo level is measured by weighing the mass of the silo and then converting this to a volume through the material density.

This requires the fitting of a load cell sensor onto to each of the support legs. Since the load sensors are installed onto the steel supports the hazard due to contact between the sensor and the product is eliminated. A load cell fitted to the silo support is shown in *Figure 2*.

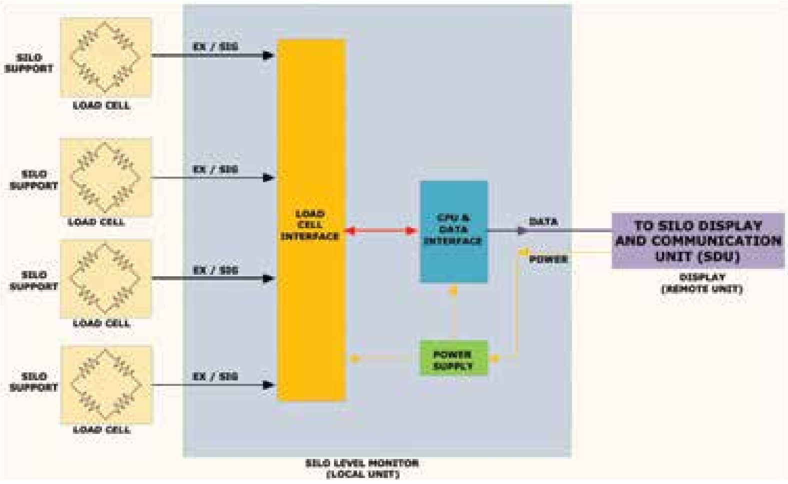

Figure 1: Bulk Explosives level monitoring.

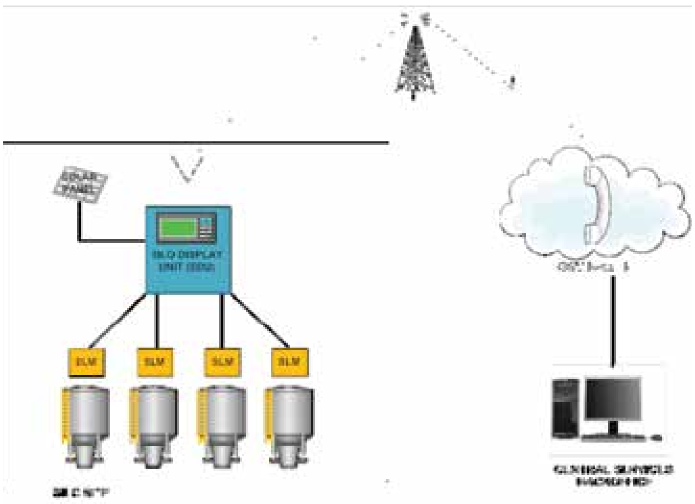

Figure 2: Silo level transmission to control room.

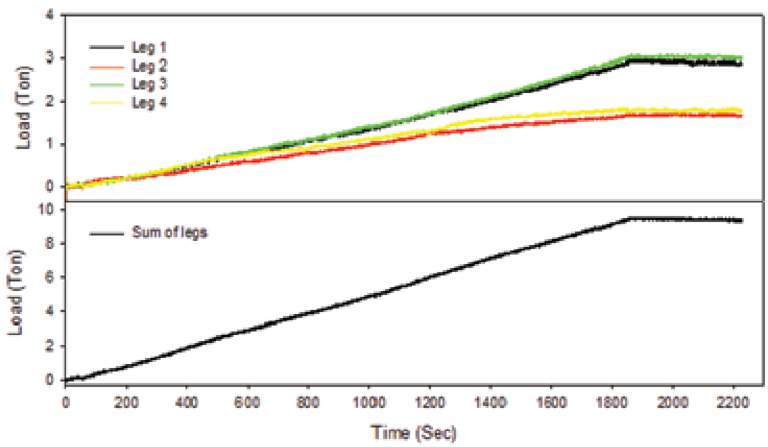

Figure 3: Load cell calibration curve.

The load cells can be located at a convenient height near the base of the silo so the hazard due to working at height is also eliminated. The load cells that were selected have been used in numerous other applications where there is high lightning activity and have proven to be reliable. There are typically four supports that need to be instrumented. The signal from each load cell is taken into a junction box on the silo. The load cell signals are then sent to the display and communications unit which can be located a safe distance from the silo. The safe distance between the silo and the display is provided by the Chief Inspector of Explosives (CIE).

The sites may have up to four silos located in close proximity as shown in *Figure 1* [8].

The signals from the individual silos are connected to a data concentrator which is connected to the display unit. The display unit provides a local indication of the silo level as well as transmitting the level data to the control room.

To convert the silo mass to a level, the equipment is calibrated by pumping a known flow rate of product into the silo. The level is measured manually and entered with the quantity of product. A calibration curve is calculated which converts the mass measured to a level. This process need to be repeated annually to ensure accuracy. A typical load calibration curve is shown in *Figure 2*.

To date the equipment has been installed at three test sites. The load cells used initially were found to be sensitive to temperature fluctuations. This problem has largely been eliminated using load cells that use additional temperature compensation. Following a full evaluation of the results and finalisation of the load cell configuration, this system will be used in all new silo installations and on silos where the ultrasonic level sensor needs replacement.

Conclusion

The application of electronic monitoring and control equipment provides for the safe storage and transfer of material in bulk explosives silos. A novel application of load cells has the potential to further reduce the existing hazard of sensor contact inside the ammonium nitrate environment by the application of non-contacting level measurement. The use of load cells can also reduce the hazards of installation and repair compared with the traditional ultrasonic sensors.

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