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Research paper

Carbon dioxide not suitable for extinguishment of smouldering silo fires: Static electricity may cause silo explosion

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ABSTRACT

Smouldering fires in wood pellet silos are not uncommon. The fires are often difficult to deal with and extinguishment is a lengthy process. Injection of inert gases to prevent oxygen from reaching the smouldering fire zone and suppress combustion is a new firefighting strategy. This article argues that injection of inert carbon dioxide (CO_2) into the silo headspace is unsafe. Carbon dioxide is generally available as a liquid under high pressure. When discharged, small particles of dry ice are formed. The rapid flow of particles can generate considerable amounts of static electricity, which can act as a source of ignition if ignitable pyrolysis gases are present. This article discusses a serious wood pellet smouldering fire and silo explosion in Norway in 2010, which took place when firefighters discharged portable CO_2 fire extinguishers into the headspace. The attempt to suppress the fire may have ignited pyrolysis gases. The article examines selected guidelines, standards, wood pellet handbooks and other literature and argues that the electrostatic hazard is widely under-appreciated. In the past, major explosions have been attributed to electrostatic ignition of flammable vapours during the release of CO_2 for fire prevention purposes. There is evidence to suggest that those early lessons learned have at least partly passed out of sight.

1. Introduction

1.1. Smouldering fires in wood pellet silos

This paper in concerned with unintended ignition of pyrolysis gases produced by a smouldering fire in a wood pellet storage confinement. Although a smouldering fire may start for several reasons, two causal pathways appear to be common:

Freshly produced wood pellets may self-heat because energy is liberated from e.g. chemical oxidation or moisture absorption. Heat loss is largely a surface-based phenomenon and because of the low surface-to-volume ratio of a large pile, any process that generates heat will slowly increase the temperature inside the pile. Pockets may form where the temperature of the contents can rise to the temperature necessary to produce spontaneous ignition. This produces an oxygen deficient smouldering fire deep inside the pile.

Wood pellets are friable and generate dust and fines when handled in the logistics chain. This dust ignites easily, e.g. from overheated electric motors or conveyor bearings, or from mechanical friction heat between conveyer belts and accumulated pellets, fines and/or dust. Small pieces of smouldering material are difficult to detect and embers may migrate in the band conveyor systems and start smouldering fires in the storage silos.

A small smouldering fire deep inside a storage silo is difficult to detect and may develop into massive storage fires and cause considerable damage to process equipment and property [1].

1.2. Pyrolysis gases

Before developing into an open surface fire, an oxygen deficient smouldering fire generates flammable pyrolysis gases rich in e.g. toxic and flammable carbon monoxide that can travel and accumulate. Pyrolysis gases may create an ignitable atmosphere in the headspace of the silo.

An internal explosion may result when the combustion zone eventually reaches the surface layer or if a source of ignition is present in the headspace. This paper is specifically concerned with potential sources of ignition introduced by firefighters.

Although this paper discusses smouldering fires in wood pellets, a smouldering fire in any type of combustible material can generate flammable pyrolysis gases.

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1.3. *Water unsuitable for smouldering fires*

Surface fires in wood pellets can be fought with water, which should be applied gently not to kick up dust and create conditions for a dust explosion. Applying water to a smouldering fire located deep inside a pile presents major practical challenges however. In addition, the usage of water has serious drawbacks. Most pellets are hygroscopic and expand when absorbing moisture. When fully saturated with water, compressed pellets may expand about 3.5 times. The wet pellets are sticky and expansion forces may lead to agglomeration and compaction creating a very hard and compact plug.

This creates difficulties during clean-up when the hard material must somehow be broken up for removal, at times requiring a jack hammer. Worse, the expansion may force agglomerations of pellet material to adhere to the walls of the silo, creating hangings or arch formation inside the silo. The sheer force of the expansion may even break the silo walls [1]. Hangings may also expose the silo walls to uneven loads for which they are not designed. There are examples of silos that have tipped over due to excessive application of water during firefighting [2].

1.4. *Alternative firefighting strategies*

The challenging nature of fighting fires in wood pellet silo and the drawbacks of using water have led research programmes to explore alternative firefighting strategies, particularly the injection of inert gases. Inert gases have the advantages of depleting the oxygen available for combustion, of quenching the pyrolysis and of lowering the risk of ignition of flammable pyrolysis gases in the headspace. The most commonly available inert gases in large quantities are nitrogen and carbon dioxide.

2. Material and methods

This article examines a case report of a serious silo explosion in Norway in 2010. The silo, which held freshly made wood pellets, experienced a deep-seated smouldering fire. The explosion took place when firefighters attempted to quench the headspace using portable CO_2 fire extinguishers. This article argues that electrostatic discharges from the release of carbon dioxide may have ignited pyrolysis gases in the headspace, resulting in the explosion.

The article examines major standards, guidelines, recent editions of frequently cited pellet handbooks and other literature, versions as per mid-2016. The article presents examples where the hazard is not stated; where the standard, guideline or recommended practice give potentially ill-advised recommendations, and where the absence of a warning may have serious consequences.

3. Theory

3.1. *Carbon dioxide and static electricity*

The ability of carbon dioxide to generate static electricity has been known for almost a century. Electrification effects associated with sliding contact between solid CO_2 and metal surfaces were reported as early as 1925. German experiments in the 1950s confirmed that static charging does not occur during the release of purely gaseous CO_2, that charging associated with the flow of liquid CO_2 is negligible and that strong charging occurs only when solid CO_2 particles are present. Butterworth and Dowling [3] provide a good overview of this early work.

3.2. *Portable CO_2 extinguishers*

A portable CO_2 extinguisher comprises a CO_2 storage cylinder, a control valve, a delivery tube and a directional horn. The storage cylinder contains liquid CO_2 under its saturated vapour pressure, which at 20 °C is 5.6 MPa. When released, the carbon dioxide undergoes a change of phase from liquid to a mixture of gas and solid. To avoid the risk of electrocution when employed against fires involving electrical equipment, the directional horn is fabricated from an electrically insulating material. Most of the charge generation is believed to occur within this horn. If the extinguisher and operator are well insulated from ground, for example by an insulating floor or by footwear, the electrostatic potential can rise to 20–30 kV within a few seconds. For some extinguisher designs, potentials up to 50 kV can be attained [3].

If the operator contacts a grounded conductor, he is likely to experience an electrostatic shock. Though the shock in itself is not hazardous, it can be severe enough to deter continuing fire-fighting action and ensuing injury is a concern. The shock could lead to a loss of balance or cause the appliance to be dropped, with potentially serious consequences if the operator were in a precarious position such as atop a ladder.

3.3. *Past explosions caused by the discharge of portable CO_2 extinguishers*

Electrostatic discharges from the release of carbon dioxide have sufficient energy to ignite flammable fuel/air mixtures and have been responsible for numerous serious accidents. In New York Harbour in 1966, an attempt to inert damaged tanks of the marine tanker vessel Alva Cape with a carbon dioxide extinguisher, caused naphtha vapours to explode, killing four men and injuring seven [4]. In another case, two firefighters were fatally injured in an explosion, which occurred while they used a portable CO_2 extinguisher to inert a tanker truck [5].

3.4. *The Bitburg disaster*

Ignition can take place even if carbon dioxide is released into steel pipework that runs underground for considerable length. A disastrous explosion took place in a JP-4 aviation fuel underground tank at a US Air Force fuel depot near Bitburg, Germany, in 1954, killing 37 people [6].

Various acceptance tests were being made on the newly constructed underground tank and its novel carbon dioxide fire extinguishing system, the first of its kind in Germany. Present were French and German officials, technicians and contractors. The roof of the underground tank was capped with iron reinforced concrete and covered with a layer of soil. Most if not all of the victims were standing on the top of the tank during a controlled activation of the thermal sensing devices that would trigger CO_2 cylinders to discharge gas into the tank's headspace.

The CO_2 cylinders were located in a half-buried concrete supply house located about 75 m from the tank and connected to the tank by a 4-inch steel pipeline which branched into two 3” pipelines that followed the circumference of the tank and terminated in four equally distanced discharge outlets. The CO_2 pipeline was buried in the ground for its entire length and the discharge outlets were installed flush with the interior tank wall surface and welded to the main steel tank. Although presumably effectively grounded, this piping arrangement conveyed electrostatically charged carbon dioxide.

One minute after the CO_2 discharge commenced, a massive explosion disintegrated the tank. The blast blew victims through the air with such force that their bodies were found between the tank and the supply house. The official investigation [6] did not identify carbon dioxide as the source of ignition; its ability to generate static electricity was only realized later [7].

3.5. *Summary*

Back in 1977, Leonard and Clark [5] succinctly summarized the knowledge available at the time, concluding that CO_2 fire extinguishers are perfectly satisfactory when used for their intended purpose, i.e.,