

Worker Hazards Associated with the Use of Grain Vacuum Systems

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ABSTRACT. *Over the past two decades, there has been more widespread use of pneumatic handling of grain at commercial grain storage facilities and on farms as these operations have increased grain storage capacity and handle larger volumes of grain and feed. In some cases, manufacturers have suggested that the use of these systems is a safer alternative to removing residual grain manually in conjunction with the use of sweep augers. The use of grain vacuum systems has also been increasingly documented as a strategy in responding to grain storage fires and human entrapment and engulfment in flowing grain. With greater utilization of these machines have come reports of entrapments and engulfments. This article summarizes 27 such documented incidents, including 21 fatalities, that resulted from the use of portable grain vacuum systems. It includes specific recommendations for engineering, educational, and regulatory strategies to reduce the risks associated with the use of these systems.*

Keywords. *Grain, Grain bin, Grain vacuum, Pneumatic, Safety, Safety devices, Vacuum.*

Even though grain vacuum systems have been successfully introduced from a technological and economic perspective into grain handling operations, their use has also introduced a relatively new form of entrapment and engulfment hazard that is not generally well recognized or understood, especially among farm operators whose increased use of grain vacuum systems has been significant.

Flowing grain entrapments include both fatal engulfments and partial entrapments that require assistance in order for the victim to be extricated. A review of the general agricultural safety literature and published research at the time this study was completed found little attention given to the potential for entrapment or engulfment while using grain vacuum systems. Only four documents were identified that focused on the potential hazards of operator entrapment while these systems were in use. An examination of commercially available systems displayed for sale and in actual use found some with no visible warnings of the potential for entrapment and some that included design features, such as the lack of an operator control at the vacuum inlet, that could lead to intentional or unintentional

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tional use that would greatly increase the risk of operator engulfment.

A content review of selected operator instructions that were provided with grain vacuum systems, obtained from online sources and manufacturers, identified few that provided specific warnings or recommended safe operating procedures for the operator, especially when the vacuum intake is used on the surface of free-flowing agricultural material (FAM). In addition, interviews with representatives of manufacturers and local suppliers of these systems found that some were unaware of the potential suffocation hazards, and a few rejected the idea that an entrapment or engulfment could actually occur to an operator while using the system in FAM. It became apparent that there was a general lack of awareness regarding the potential hazard of entrapment while using these systems.

In the original NIOSH Alert on preventing entrapment and suffocation caused by unstable surfaces of stored grain and other materials (NIOSH, 1987), there was no mention of the potential hazards of grain vacuum systems. A second NIOSH Alert (NIOSH, 1993) warning farmers of the deadly risks of grain suffocation also did not address the potential of entrapment while using vacuums on the surface of grain. A more comprehensive NIOSH publication (NIOSH, 1995) on safe grain and silage handling also did not recognize grain vacuum hazards.

A 1998 report from the Iowa Fatality Assessment and Control Evaluation Program (Iowa FACE, 1998) focused on a 64-year-old farmer and owner of a grain vacuum service who died while using a grain vacuum system to remove corn from a 352.4 m³ (10,000 bu), 9.1 m (30 ft) diameter bin. This was the first professionally documented incident involving a grain vacuum system identified in the literature. The corn was reported to be in good condition, but the infloor outlet became plugged, requiring an alternative approach to emptying the bin. The victim became engulfed when he operated the intake of the vacuum on the surface of the grain and removed the grain from beneath his feet. The report recommended that:

- Employers and grain handlers should ensure that safe confined-space entry practices are followed when entering grain bins.
- Grain vacuums should have an emergency stop device.
- Grain vacuum operators should be made aware of hazardous conditions caused by spoiled or clumped grain.
- Grain vacuum operators should follow manufacturer's guidelines for safe operation, including working at a shallow angle and moving the vacuum intake frequently.

In 1998, following the Iowa FACE report and other reported incidents of fatal engulfments in FAM, NIOSH issued a "Hazard Alert" bulletin (NIOSH, 1998) regarding the use of grain vacuum systems. NIOSH recommended that grain vacuums be equipped with an emergency shut-off at the operator station, or intake of the vacuum. In addition, NIOSH recommended that grain vacuum operators be made aware of hazardous conditions caused by out-of-condition grain, including exposure to airborne dust, mold spores, and endotoxins, and to frequently move the vacuum intake to prevent the formation of depressions in the grain surface, which could become points of entrapment.

A second Iowa FACE report was released in 2011 that provided a description of a fatality involving the use of a grain vacuum by a 70-year-old male farmer. Recommendations to prevent such incidents did not specifically address the use of grain vacuums but rather general grain bin entry procedures, such as placement of warning labels, limiting access, use of confined-space entry procedures, and breaking up crusted grain from outside the bin (Iowa FACE, 2011).

Purdue University's Agricultural Safety and Health Program, through its efforts to document injuries and fatalities resulting from worker exposure to agricultural confined spaces, has been documenting incidents since 1987 involving the use of grain vacuum systems, several of which were reported as fatal (Freeman et al., 1996; Kingman et al., 2003; Roberts et al., 2012; Riedel and Field, 2011a).

As the use of grain vacuum systems continues to expand, there is a need to raise the awareness of the potential risks of these systems and to explore the need for recommended safe work practices and engineering design standards to reduce the risk of injury or death, especially on farm operations, many of which are exempt from federal grain handling and confined-space entry regulations. Currently, most farm operations (including those with ten or fewer employees) are considered exempt from the enforcement of federal grain handling and confined-space entry regulations due to the exemptions included in the relevant standards and restrictions placed on the Department of Labor by Congress in the budget appropriation language.

The purpose of this article is to summarize both fatal and non-fatal incidents documented to date and to begin the discussion regarding initiatives needed to reduce the likelihood of future incidents.

Background

The use of air or pneumatic material handling systems dates back to the 19th century, when such systems provided efficient mail transport for postal services and for moving documents within large buildings prior to electronic communications (Museum of RetroTechnology, 2008). As these systems were refined, they began to be applied to a wider variety of uses. Pneumatic conveying was eventually used for loading and unloading ships and barges, handling sewage and other wastes, installing insulation in the construction industry, handling cement, sugar, and flour, as well as grain industry applications.

The on-farm application of pneumatics has been well documented for over half a century. The earliest uses included moving chopped corn with an impeller to fill silos and blowing straw away from threshing machines (Kleis, 1955). Feed and supplement suppliers delivered their products to farms in trucks equipped with pneumatic pumps that were used to blow the material relatively long distances to conveniently located storage structures. Initially, these systems were seen as material transporters, with the "working end" being the outlet rather than the inlet, which was typically stationary or semi-stationary.

The commercial grain industry quickly recognized the benefits of pneumatic grain handling as the volumes of grain handled, especially for export, grew rapidly during the 1970s. Large stationary vacuum systems were developed and installed at terminal elevators and ports to load and unload ships and barges. These systems greatly increased handling capacity and reduced turnover time of storage and transport facilities.

Initially, the selection of vacuum systems as a means of handling grain had little to do with worker health or safety but rather the advantages of these systems to move large volumes of grain quickly. As their use was further researched, they were found to be beneficial in handling delicate, high-end seeds and products such as popcorn and seed corn, where kernel integrity is important. In some cases, they were found to be more efficient than augers and drag conveyors when the speed of grain flow was a priority (Robertson, 2010). However, pneumatic systems require more power than mechanical systems such as augers and conveyers, making them less energy efficient (Atkins and Wiens, 1982). In

many operations, a combination of mechanical and pneumatic systems is used based on which system produces the best results. Pneumatics might be used where access is difficult, such as bin cleaning, or when speed of grain flow is essential, and mechanical systems might be used where large volumes are moved from one site to another.

As worker health, safety, and comfort considerations became more important, it was found that grain vacuum systems could reduce the physical labor required to remove residual grain from storage facilities and to clean up spilled grain. Workers could enter grain storage structures to remove grain without the need for exposure to active mechanical equipment, such as in-floor and sweep augers or drag chains (Robertson, 2010). This work was traditionally done manually, with shovels and brooms, and if out-of-condition grain was involved, it was dirty and exhausting work. One report recommended that grain vacuums be used to reduce dust exposure that occurs during manual removal of grain and claimed that dust exposure caused lung disease (CCHSA, 1999). However, this reduction of dust was only shown to be documented at the point of intake, while the system outlet generated significant levels of airborne dust (Atkins and Wiens, 1982). Cyclone dust collectors have been demonstrated to reduce the amount of dust released into the atmosphere. They are found in most commercial applications of grain vacuums due to current requirements to reduce dust emissions, and they are also required in non-exempt facilities to reduce the risk of fire and dust explosion.

When initially introduced, grain vacuum systems were seen as labor-saving devices and enhancements to efficiency. Little evidence of their potential hazards was identified in the historical record of these systems. As noted earlier, the first NIOSH Alerts on the hazards of flowing grain (NIOSH, 1987, 1993) did not mention hazards associated with grain vacuums, and the OSHA Grain Handling Facilities Standard (CFR 1910.272) did not include provisions for their use. As the technology of grain vacuum systems developed and smaller, high-capacity, portable systems were introduced, consolidation of grain farms was also rapidly taking place. Both cash grain and livestock operations were expanding their acreage and their grain storage capacity to capture the economic benefits of strategic marketing of grain and to control feed costs. In some cases, on-farm storage facilities became as large as many commercial elevators, and some farmers purchased local commercial facilities that commercial grain dealers considered obsolete or too small to remain profitable. Some of these facilities came equipped with pneumatic grain handling systems. Alternatively, farmers recognized the value of such systems, and suppliers quickly stepped in to meet the need. Even though no data were found on the prevalence of grain vacuums on farms, the presence of manufacturers of these systems at farm trade shows, their coverage by the farm media, and the availability of online resources and marketing material strongly support the position that the number of these systems on both commercial and farm operations is continuing to grow. Consequently, the exposure that workers have to these systems, and the potential for injury from mechanical hazards and entrapment in FAM, will also continue to increase (Riedel and Field, 2011b).

Current Manufacturers of Grain Vacuum Systems

Currently, there are no fewer than nine manufacturers that market grain vacuum machines for distribution in North America. These include both domestic and foreign manufacturers, which may operate under different engineering and safety standards. Current manufacturers include the following:

- Brandt (Regina, Saskatchewan, Canada; www.brandt.ca).

- Bruning (Shelbyville, Indiana; www.bruningenterprises.com).
- Christianson (Blomkest, Minnesota; www.christianson.com).
- Farm King (Winnipeg, Manitoba, Canada; www.farm-king.com).
- Kongskilde (Hudson, Illinois; www.kongskilde.com).
- Neuero (West Chicago, Illinois; www.neuero.com).
- Thor Conveyair (Winnipeg, Manitoba, Canada; 204-982-8350).
- REM (Swift Current, Saskatchewan, Canada; www.rementerprisesinc.com).
- Walinga (Wayland, Michigan; www.walinga.com).

Basic Design of Grain Vacuum Systems

Grain vacuums are available with one of three power sources: tractor-operated power takeoff (PTO), engine-mounted units, or electric motor. Portable, tractor-operated PTO systems are the most common (fig. 1) for farm applications with capacities of 8.8 to 52.9 m³ h⁻¹ (250 to 1,500 bu h⁻¹). Some larger commercial facilities use grain vacuum machines that are capable of moving grain at rates between 52.9 and 352.4 m³ h⁻¹ (1,500 and 10,000 bu h⁻¹), depending on the power source and grain type. Salvage operations may use truck-mounted or semi-stationary units. These systems operate at power levels from 74.6 to 134.2 kW (100 to 180 hp). Grain vacuum systems generally contain the following primary components: a power source, intake pipe, intake air valve, discharge pipe, blower, air lock, and cyclone separator (fig. 2). Intake hoses are made of various materials, including solid and flexible metal tubing and rigid rubber hoses. The blower provides suction and discharge, drawing grain in through the intake hose and discharging it through the air lock and cyclone separator. The cyclone separates the grain from the air and pushes the grain out through the discharge pipe. Manufacturers produce variations of



Figure 1. PTO-operated grain vacuum machine.

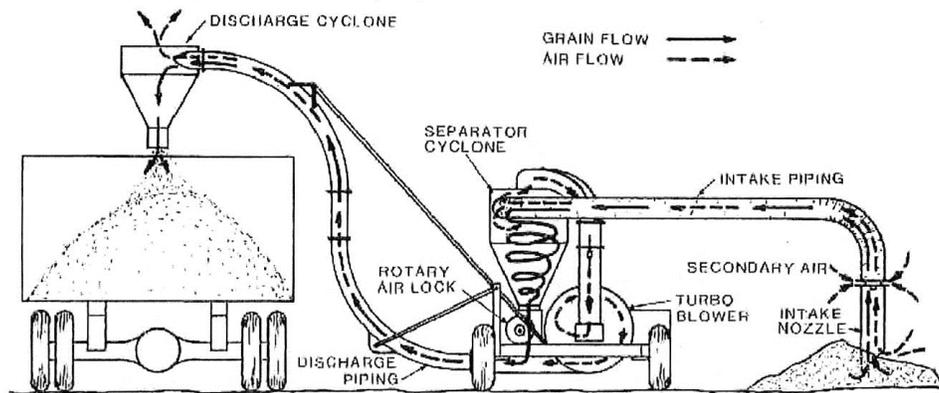


Figure 2. Schematic of pneumatic conveyor showing air and grain flow (Atkins and Wiens, 1982).

these systems; for example, some do not use a cyclone separator yet contain the other primary components. Examination of several types of systems currently in use found that some have no means of controlling intake capacity at the inlet, such as a shut-off control or slide valve to allow additional air to enter the intake to reduce the suction.

Applicable Standards

Currently, there are no published engineering design standards nor consensus, evidence-based workplace safety practices that specifically address the general use of grain vacuum systems in agricultural settings. No evidence could be found that the manufacturers of these systems have collectively pursued the development and publication of standards that would enhance the safety of these systems. However, several published engineering standards would apply if these systems were identified as either agricultural or farmstead equipment. These include:

- ASAE S304.8: Graphical symbols for operator controls and displays on agricultural equipment.
- ANSI/ASAE S493.1: Guarding for agricultural equipment.
- ASAE S441.3: Safety signs.
- ANSI/ASAE S318.17: Safety for agricultural field equipment.
- ANSI/ASAE S354.5: Safety for farmstead equipment.

Hazards Associated with Grain Vacuum Systems

As with any complex system involving mechanical, electrical, or hydraulic components, grain vacuum systems present a number of potential hazards to operators. An examination of currently available grain vacuum systems suitable for on-farm applications and a review of operator's manuals for grain vacuum systems available at the time this study was conducted identified the following potential hazards to users:

- Exposure to operating or unguarded PTO components.
- Exposure to dust near the discharge spout.
- Potential for entrapment in grain when the vacuum inlet is near the operator's feet.
- Potential for entrapment when the vacuum inlet is left too long in one location, creating a cone or depression that could cause an avalanche of free-flowing grain.
- Potential for other workers on the grain surface to be entrapped during grain movement.

- Potential for contact with overhead electrical wiring.
- Exposure to high sound levels.
- Potential for separation at towing transport speeds above 32 km h⁻¹ (20 mph).

Entrapment Process while Using Grain Vacuum Systems

The process of entrapment while using a grain vacuum system involves several contributing factors that many farmers and commercial grain operators may not be aware of or fully understand, or in some cases choose to ignore. During use, the flow of grain into the vacuum intake is so fast that it can remove the grain beneath the operator's feet, pulling the operator down and causing entrapment without warning or before an appropriate response can be made. The operator can become entrapped in flowing grain beyond the point of self-extrication in as little as 15 s during normal unloading procedures (Roberts et al., 2011). If grain removal has submerged a victim to waist level or deeper before the flow of grain is stopped, attempting to pull the victim out can result in serious injury, including joint dislocation and damage to the spinal column (Roberts et al., 2011).

During recommended vacuum unloading procedures, the operator moves the inlet frequently to maximize efficiency. However, if the inlet is left long enough in one location, the vacuum can rapidly create a depression that the operator can slip into, and then become entrapped under the inflowing grain or pulled farther down by the grain flow (fig. 3). In one case, an observer watched helplessly from the outside of the bin while a



Figure 3. Illustration of a vacuum causing a cone depression in the grain.

grain vacuum operator disappeared beneath the surface of the grain after placing the inlet pipe at his feet to rest. The observer had to climb down a 9.1 m (30 ft) bin ladder and reach the tractor in order to shut off the power supply to the vacuum pump because there was no means to control the vacuum at the operator's station. The victim had been buried beneath the surface of the grain for 2 to 3 min before the flow of grain could be stopped, causing the victim to suffocate.

To better understand the engulfment process, a test was set up at the Purdue University Post-Harvest Grain Storage Center in which a small bin of corn and a grain vacuum system were used to demonstrate engulfment speed. The bin was an open-top corrugated steel structure used for grain bin rescue demonstrations, and it contained a floor grate to prevent full engulfment of anyone in the bin. The medium used was dried corn at or below 14% moisture. A $42.3 \text{ m}^3 \text{ h}^{-1}$ (1,200 bu h^{-1}) capacity PTO-operated grain vacuum system was used to draw the grain out of the bin using a flexible hose and a hand-operated intake. With the operator standing on the surface of the grain holding the intake, the vacuum system was activated. When the intake was placed at the operator's feet, it took less than 15 s for the operator to be drawn into the grain beyond the point of self-extrication (fig. 4). The speed of entrapment was surprising to both the operator and the observers. However, considering that the vacuum system was removing approximately $42.3 \text{ m}^3 \text{ h}^{-1}$ (1,200 bu h^{-1}) or approximately $0.011747 \text{ m}^3 \text{ s}^{-1}$ ($1/3 \text{ bu s}^{-1}$), the speed of a body, comprised of about 0.07048 m^3 (2 bu) by volume, entering the grain mass should have been anticipated.



Figure 4. Demonstration of the rate of human entrapment by a grain vacuum system.

Identifying Grain Vacuum System-Related Entrapments and Engulfments

Purdue University's Agricultural Safety and Health Program has been conducting surveillance of FAM-related entrapments and engulfments for over 30 years. Incident data have been entered into a computer database called the Purdue University Agricultural Confined Space Incident Database (Freeman et al., 1996; Kingman et al., 2003; Roberts et al., 2012; Riedel and Field, 2011a; Issa et al., 2013). Currently, the database contains information on over 1,600 individuals who were involved in an agricultural confined-space incident. Of these cases, over 1,000 involved FAM and approximately 60% were fatal (Issa et al., 2014). Information in the database is based on news reports, death certificates, police reports, NIOSH FACE reports, voluntary reporting, and documentation related to civil litigation. The database is not considered comprehensive, with estimates that the surveillance process underreports all incidents by 20% to 30%, especially with respect to non-fatal entrapments (Roberts et al., 2012).

All documented cases were reviewed for any reference to a grain vacuum machine or pneumatic grain handling system in use at the time of the incident. Keywords were used to conduct the search, and all relevant cases were further reviewed using original sources. This review included both initial entrapments and use of grain vacuums as part of an emergency response strategy. Roberts et al. (2011) reported on findings related to rescue strategies using grain vacuums.

Summary of Documented Grain Vacuum System Related Incidents

No cases of entrapment or engulfment while using a grain vacuum system were identified prior to 1987. This probably reflects lower use prior to that time and an introductory period during which these systems began to be adopted. However, it is highly probable that earlier incidents occurred but were not reported. Since 1987, there have been no fewer than 27 documented entrapment incidents directly related to the use of grain vacuums. In addition, 40 incidents were documented in which a grain vacuum was used as part of an extrication strategy. Note that 1988 and 1989 had four and three entrapment cases, respectively, and all were fatal. No year since has had more than two cases. In addition, there have been reports of other cases, including partial entrapments of first-responders while using a vacuum during victim extrications from FAM. However, these cases were not documented sufficiently to include in the database (table 1).

Of the 27 documented cases, 21 (78%) were complete engulfments resulting in fatalities. As noted earlier, there is a strong probability that there were additional unreported, non-fatal entrapments not discovered by the Purdue surveillance effort. Nine of the cases were documented in Iowa, where the first cases were reported by state and federal sources (fig. 5). Iowa also ranks as the state with the most documented incidents involving agricultural confined spaces, including grain storage (Roberts et al., 2012). All but one of the victims was male, with an average age, when age was known, of 46. The majority of the victims were employees of commercial grain operations, with no more than three incidents identified as occurring on an OSHA exempt farm operation.

In all cases, the vacuum system was activated and removing grain at the time of the incident. Even though most of the incident reports were incomplete, in at least 12 of the cases it could be determined that the victim was operating or standing next to the vacuum inlet while standing on the grain surface within a grain storage structure. In the remaining cases, it could not be determined if the victim was operating the grain vacuum intake, but

Table 1. Grain vacuum system incident summary.

Year	Sex	Fatal	Location at Time of Incident
1987	Male	Yes	Grain bin
1988	Male	Yes	Grain bin
1988	Male	Yes	Grain elevator
1988	Male	Yes	Commercial grain bin
1988	Male	Yes	Grain bin
1989	Male	Yes	Commercial silo
1989	Male	Yes	Commercial grain bin
1989	Male	Yes	Commercial flat storage structure
1993	Male	Yes	Commercial flat storage structure
1994	Male	No	Commercial Quonset hut
1996	Male	Yes	Grain bin
1996	Male	Yes	Grain bin
1998	Male	Yes	Silo
1998	Male	Yes	Grain bin
1999	Male	No	Commercial grain bin
2001	Male	Yes	Grain bin
2003	Male	No	Grain bin
2004	Male	Yes	Commercial silo
2004	Male	Yes	Commercial grain bin
2006	Male	Yes	Silo
2006	Male	No	Commercial grain bin
2007	Male	No	Commercial silo
2008	Male	Yes	Commercial grain bin
2008	Male	No	Commercial flat storage
2010	Male	Yes	Silo
2011	Female	Yes	Corrugated steel bin
2012	Male	Yes	Grain bin

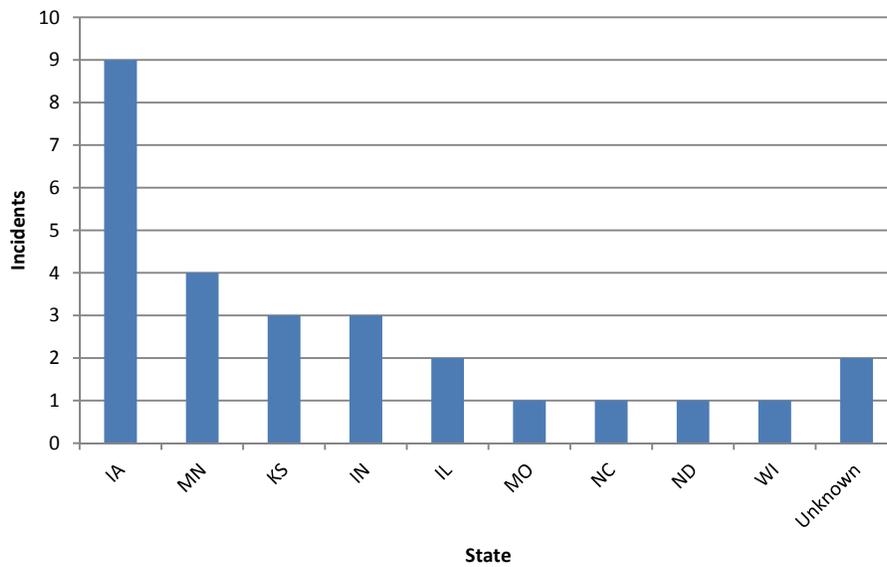


Figure 5. Documented grain vacuum incidents by state.

it was determined that all the victims were in close enough proximity to the intake to cause entrapment. In three cases, the victim was reported to have been standing on the floor of the structure, vacuuming grain from a standing pile, when grain avalanched down the face of the pile, causing entrapment.

As noted in other studies (Kingman et al., 2003; Riedel and Field, 2011b), out-of-condition grain was documented as a contributing factor in several of the cases, and was likely a factor in most of the cases. In the documented cases, the grain vacuum operators were standing on crusted or out-of-condition grain, attempting to break it up and remove the damaged grain prior to unloading. Cases were also identified in which the primary outlet or well of the structure was plugged, and the grain vacuum system was being used as an alternative means of removing the grain.

There was insufficient evidence to draw any meaningful conclusions about the use of personal protective equipment or compliance with required confined-space entry procedures when applicable. According to the available case reports, none of the victims were identified as using a rope or harness, and only four cases mentioned an observer present. Nearly all of the documented incidents occurred at commercial, OSHA non-exempt facilities, where compliance with the OSHA Grain Handling Facilities Standard (CFR 1910.272) should have been required. Again, as noted earlier, the information available is not comprehensive, and drawing valid conclusions from the data is problematic.

Case Studies

There are few well-documented case studies currently available in the literature. The five brief case studies reported below were selected to represent the different settings, victim ages, and facilities involved in entrapments involving grain vacuum systems. Each has been documented with original reports, including NIOSH and police reports.

Illinois

In 1988, a 17-year-old farm employee suffocated in flowing grain while using a grain vacuum. Employees were vacuuming corn from a flat grain storage facility into a truck. Two employees positioned themselves inside the building, while a third employee operated the machine from the outside. The victim and his co-worker were standing on about 3 m (10 ft) of grain. The victim was trying to pull the 15 cm (6 in.) hose out of the grain to move it to another location when he lost control of the hose. This caused the inflow of grain to form a cavity at the vacuum intake. The vacuum pulled grain from under the victim's feet, causing him to be drawn down into the grain and completely buried, resulting in suffocation and death.

Iowa

In 1998, a 64-year-old farmer was vacuuming corn out of a 352.4 m³ (10,000 bu) bin when he was sucked down into the grain and suffocated. He was using the vacuum because the unloading auger had malfunctioned or was plugged. The victim had already vacuumed out four truckloads of corn when the entrapment occurred. He and his co-worker were operating a PTO-powered vacuum system with a 111.9 kW (150 hp) tractor. They had connected a 15 cm (6 in.) hose to the vacuum system. The process involved sucking up grain with the vacuum at a shallow angle throughout the bin to maintain a level surface. This required the operator to move the vacuum tube frequently. The victim had been using this particular grain vacuum for four years and was experienced with this

type of grain removal. His co-worker was outside the bin, operating the vacuum system. When the co-worker entered the bin to check on the victim, the victim was nowhere to be seen. However, the vacuum was still running and had created a cone depression where it was last placed. The victim's co-worker located him using a stick to probe the corn. He was found submerged under 1 m (3 ft) of corn, lying horizontally, with his feet pointing toward the vacuum tube. After attempted resuscitation, he was pronounced dead at the scene (Iowa FACE, 1998).

Kansas

In 2006, two grain elevator employees were using a grain vacuum to remove grain from a silo when one of them became entrapped. Employee 1 was inside the bin, handling the vacuum inlet, while employee 2 was outside operating the machine. Suddenly, the vacuum inlet became stuck in the grain. When employee 1 tried to remove it, he was pulled into the grain as it was sucked out from underneath him. He called for help, and employee 2 came to assist, trying to shovel his co-worker out of the grain. When that failed, he called for help but could not be heard over the sound of the vacuum. Employee 2 then left the silo and had another employee call 911. By this time, employee 1 had become entirely engulfed by grain. When rescue personnel arrived, hoses were used to suck out the grain and uncover the victim. After being entrapped for approximately 35 min, employee 1 was successfully pulled from the grain and survived.

Minnesota

In 2010, a 55-year-old farmer suffocated when he was engulfed in grain inside a metal bin while using a grain vacuum to remove corn. It is believed that the victim entered the bin to do some clean up while the bin was being unloaded with the bottom auger. The wet grain had frozen, and a top layer had crusted over. As the farmer walked on the top of the grain, he broke through the crust and slipped into the pocket beneath the grain surface that was formed by the removal of grain from the bottom of the bin. He was pulled down farther into the grain as both the auger and the vacuum continued to cause the grain to flow from underneath the victim. The victim became completely engulfed, with no one to observe or respond to his situation.

Iowa

In 2012, a 60-year-old farmer was using a grain vacuum to remove seed beans from a metal grain bin. The soybeans were being transferred to a waiting truck. With the truck driver outside the bin, the farmer entered the bin through the center portion of a side access door that was approximately 1 to 1.2 m (3 to 4 ft) from the floor. An employee arrived later and found the farmer completely engulfed except for his arm. He was unable to rescue the man on his own. First-responders extricated the farmer but were unable to revive him.

Use of Grain Vacuums in Entrapment Rescues

Since 1992, there have been no fewer than 41 documented grain rescue attempts involving the use of grain vacuums. Based on news reports, it is assumed that the actual number is much higher. In the documented cases, rescue efforts were successful in 26 cases, while in 15 cases a fatality was reported, assumed to be the initial victim. Over the past three to five years, there have been extensive training efforts across the U.S. on

appropriate grain rescue strategies, including the use of grain rescue containment devices such as grain rescue tubes (figs. 6 and 7). During this training, fire departments and other rescue personnel are instructed to employ grain vacuums to remove grain from within the grain rescue tube and/or to remove grain from the structure to access the victim. The use of vacuums in grain rescue attempts has clearly increased in recent years, most likely due to the greater access to these machines and instruction in their use as a rescue strategy. Only ten rescue attempts involving the use of a vacuum were documented before the year 2000. Since then, 31 vacuum rescue attempts have been documented (fig. 8).

However, very little information is available on the safe use of grain vacuum systems by first-responders. The potential for inappropriate use appears high, especially where there is a lack of personnel trained in the use of these machines. At least one case was identified in which a first-responder became a secondary victim during the use of a vacuum to remove the primary victim.

Conclusions

This preliminary study identified at least 27 incidents in which an operator or bystander of a grain vacuum system became entrapped in FAM, and at least 21 of these incidents resulted in a fatality. However, the current reporting and documentation of FAM entrapments is not comprehensive enough to determine the actual frequency of incidents involving grain vacuum systems nor to ascertain causative factors. As with FAM entrap-



Figure 6. A grain vacuum used in an attempt to rescue a man entrapped in a bin on an Indiana farm.



Figure 7. A fire rescue team trains to use a grain vacuum and tube for entrapment rescue attempts.

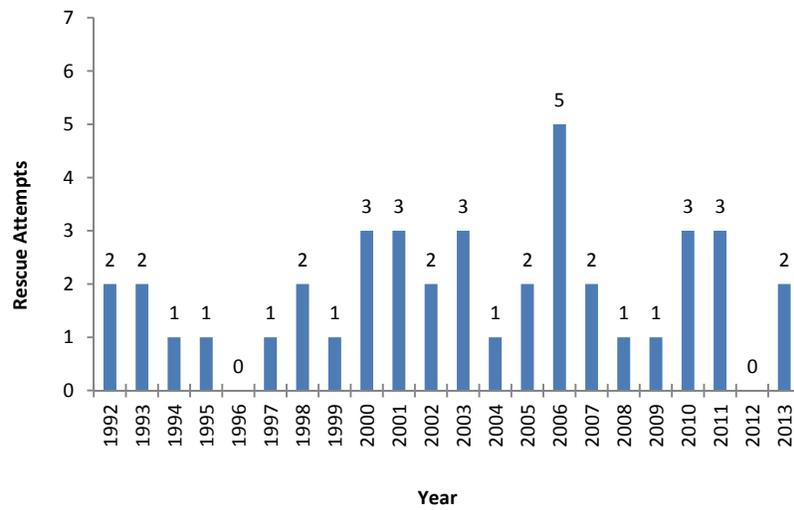


Figure 8. Documented grain vacuum rescue attempts by year.

ments in general, it can be estimated that the majority of grain vacuum related incidents occur in the Corn Belt, involve males, occur in metal storage bins, involve out-of-condition corn, and result in a disproportionate number of fatalities. However, unlike other FAM cases, over half of which occur in OSHA exempt facilities, the majority of documented grain vacuum cases have occurred in non-exempt or commercial facilities.

Both OSHA exempt farm operations and non-exempt commercial grain operations are expanding their use of grain vacuum systems, and it is highly probable that their use will increase in both applications. The increased use of these systems will possibly increase the incidents of entrapment associated with their use, as reflected in the data.

The general level of awareness of the risk of entrapment and engulfment for the operators of grain vacuum systems, as evidenced in the general and research literature, is not adequate for the manufacturers and distributors of these systems, nor for their owners and users. There appears to be little attention being given in either the general agricultural safety literature or the operator instructions provided by the manufacturers regarding precautions that should be taken to prevent entrapments or engulfments.

The general design characteristics of grain vacuum systems, in conjunction with the lack of awareness of the potential for entrapment or engulfment, have contributed in the past to cases of entrapment and engulfment. This includes, in some cases, the lack of a control mechanism at the vacuum intake that would allow emergency shutoff, and the lack of adequate warnings on the machine or in the operator instructions.

Even relatively small-capacity grain vacuum systems have the potential of entrapping and/or engulfing an operator. The speed of grain removal, even for smaller systems of less than $42.3 \text{ m}^3 \text{ h}^{-1}$ ($1,200 \text{ bu h}^{-1}$) capacity, is so fast that in some situations self-extrication becomes difficult or impossible within a minute or two.

The use of grain vacuum systems has been demonstrated to be an effective strategy for responding to entrapments and engulfments in FAM. However, first-responders are at risk of secondary entrapments if they are not aware of the potential for rapid entrapment. Therefore, they should be trained in the safe use of grain vacuum systems.

Recommendations

There is a need not only to continue documenting incidents involving grain vacuum systems but also to enhance the comprehensiveness of the data in order to gain a better understanding of causative factors and to identify trends, such as those related to out-of-condition grain. Currently, most grain storage operations in the U.S. are exempt from injury reporting requirements, which will have to change if better data are to be gathered.

Steps should be taken by both agricultural safety and health professionals and manufacturers of grain vacuum systems to raise the awareness level of operators to the potential risks for entrapment and other system-related hazards, such as exposure to airborne toxic dust. These efforts should include media releases to the farm press, online resources, inclusion of information on grain vacuum systems in other grain handling safety resources, and expanded safety information in operator manuals and on-machine instructions.

Manufacturers, in conjunction with the American Society of Agricultural and Biological Engineers (ASABE), should develop appropriate engineering and practice standards for future designs of grain vacuum systems. This effort should include compliance with current applicable standards, inclusion of appropriate warnings in operator instructions

and on the machines, and incorporation of an intake control mechanism that can be used in the event of an emergency to stop or diminish the flow of grain into the machine.

Information on the potential hazards of grain vacuum systems used during rescue attempts from grain entrapment and engulfments should be incorporated into current grain rescue training resources.

Clarification is needed from the U.S. Department of Labor (OSHA) on the application of the provisions of the Grain Handling Facilities Standard (CFR 1910.272) to the use of grain vacuum systems within grain storage and handling facilities. The OSHA-recommended use of grain vacuums to remove residual grain in order to reduce exposure to unloading augers should be re-evaluated in light of the potential for entrapment.

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