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# A HAZARD AND OPERABILITY STUDY OF ANHYDROUS AMMONIA APPLICATION IN AGRICULTURE

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*Researchers from the National Institute for Occupational Safety and Health (NIOSH) applied Hazard and Operability (HAZOP) analysis to examine hazards during the use of anhydrous ammonia by farmers. This analysis evaluated the storage, transfer, and application of anhydrous ammonia, identifying credible hazard scenarios, practical solutions, and research needs. Ninety-five findings were developed that are of use to farmers, distributors of ammonia and application equipment, and manufacturers of application equipment. The findings generally involve training, equipment design changes, preventive maintenance, and material compatibilities. The HAZOP team found that additional safety features need to be developed or implemented. The study also pointed out where correct operator procedure and preventive maintenance can prevent inadvertent releases. Other inadvertent releases are caused by incompatible materials, or by using equipment in ways other than intended. Several examples of the findings are given to emphasize the HAZOP technique and the high-risk scenarios. Strategies for dissemination to the agricultural community are presented.*

**A**nhydrous ammonia is widely used in the agricultural community as an inexpensive fertilizer. It is the third largest volume chemical produced in the United States, with 30% of this volume used as a fertilizer. Anhydrous ammonia is supplied to the farmer as a liquefied gas, typically in thousand-gallon quantities. There are no known national databases that record injuries and/or deaths due to anhydrous ammonia. Any information available is lumped into broad categories from which specific information concerning anhydrous ammonia cannot be retrieved. However there are anecdotal accounts of deaths and injuries from anhydrous ammonia releases. Because of these, and the fact that there is a potential for the formation of toxic vapor

clouds of ammonia from catastrophic leaks, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted a Hazard and Operability study (HAZOP) on anhydrous ammonia application in agriculture. HAZOP, a methodology of process hazard analysis (PHA), systematically evaluates the components of a system for potential safety and operability deficiencies.

Outside of agriculture, there are few (if any) other industrial pursuits where such a large population of relatively untrained workers employs such an assortment of hazardous materials or equipment ranging from anhydrous ammonia to pesticides to large agricultural equipment. These factors, therefore, make the development, dissemination, and implementation of practical and effective preventive measures, such as this HAZOP, extremely important and challenging. In this paper, a description of suggested dissemination approaches is presented.

## HEALTH EFFECTS OF ANHYDROUS AMMONIA

The health effects of anhydrous ammonia for humans are clearly dependent on the concentration of the exposure. Injuries resulting from exposures to anhydrous ammonia accidents may result in skin burns, pulmonary congestion, partial or total blindness, or death. The Occupational Safety and Health Administration (OSHA) Short-Term Exposure Limit (STEL) is 35 ppm (over a 15 minute interval).<sup>(1)</sup> The NIOSH Recommended Exposure Limit (REL) is 25 ppm TWA for 8 hours and a 35 ppm STEL.<sup>(2)</sup> Table I summarizes the general effects for different exposure levels.

## ANHYDROUS AMMONIA AND ITS APPLICATION

Anhydrous ammonia is the most concentrated nitrogen source available from a fertilizer.<sup>(3)</sup> It is usually applied 6 to 8 inches below the soil surface, vaporizing quickly as it is released. After application, the anhydrous ammonia is oxidized in the soil first to nitrites and then to nitrates, which are easily absorbed by plant roots as a fertilizer. Nitrogen

Mention of company name or product does not constitute endorsement by the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

**TABLE I. Health Effects of Anhydrous Ammonia<sup>(7)</sup>**

$NH_3$	General Effect	Exposure Period
< 1-50	Odor detectable for humans	Immediately
20-50	Dryness of the nose, possible eye and respiratory irritation	5 minutes
134	Eye irritation with tearing, nose and throat irritation	5 minutes
500	Upper respiratory irritation lasting up to 24 hours and tearing (though no direct eye contact)	30 minutes; exposure by means of an oral-nasal mask
> 500	Effects may range from compulsive coughing and severe eye irritation to death	Occurs in emergency situations; duration and concentrations have not been recorded

stabilizers are often added to the anhydrous ammonia before application. These stabilizers retard the breakdown of the ammonia so the crop can use the nitrogen. The stabilizers reduce nitrogen losses by reducing the amount of nitrogen leaching into the soil beyond plants' reach and by reducing the amount of nitrogen escaping to the atmosphere.

Anhydrous ammonia can be applied at various times of the year—in spring before planting, in summer on already growing crops, and in fall or winter. Anhydrous ammonia applicator tanks range in size from 250 to 2000 gallons. Such large quantities of a volatile, toxic material presents the potential for injuries or fatalities. Anhydrous ammonia is transported from the manufacturer to the retail distributors where farmers can buy or rent application equipment and purchase anhydrous ammonia. Many of these retail distributors also serve as feed-and-seed or general stores.

In preparation for this HAZOP analysis, several applications of anhydrous ammonia were observed. Based on these observations, the preventive maintenance of the equipment seemed to be the responsibility of the owner of the equipment. When using rented equipment, however, the farmer usually handles minor maintenance problems that may occur during application.

The retail distributors store anhydrous ammonia in 5000 to 90 000 gallon tanks. The retailer owns many smaller tanks that are filled with anhydrous ammonia and are used to apply it on the fields. The larger-sized applicator tanks, typically of 1000 to 2000 gallon capacity, are often referred to as "nurse tanks." The farmer can use the larger nurse tank during direct application to the crops, as is typical in the midwestern United States, or use the nurse tank to fill a smaller applicator tank. The smaller applicator tanks

typically range from 250 to 550 gallons. An employee of the retail distributor or a farm worker transports the tank and other equipment to the farm for use.

The application equipment consists of a trailer-mounted applicator tank, a toolbar to hold the applicator knives, hoses and flow regulators, valves, and a flow distributor to split the anhydrous ammonia flow leading to the individual knives. The filled applicator tank and trailer are directly attached to a toolbar, which is connected to the tractor. Typically, the applicator tank is

filled at the retail distributor. If nurse tanks are used to fill smaller applicator tanks, the filling is often done on the farm. Applicator tanks are designed to be filled only to 85% of their capacity to allow for vapor expansion. Figure 1 illustrates a tractor attached to a toolbar with applicator knives, and a nurse tank, which is attached to a smaller applicator tank. More typically, the nurse tanks are pulled behind larger, modern tractors that also are equipped with rollover protection.

## METHODS

The HAZOP technique systematically reviews the components of a process for potential hazards.<sup>(4)</sup> It is a rigorous and powerful technique for identifying complex failure scenarios involving multiple independent events. The HAZOP analysis is specifically mentioned as a methodology of PHA satisfying the newly promulgated OSHA Process Safety Management regulations for systems containing specified amounts of "highly hazardous substances."<sup>(4)</sup> Retail outlets storing more than 10 000 pounds (approximately 1970 gallons) of anhydrous ammonia would be covered under OSHA's regulations requiring a PHA.

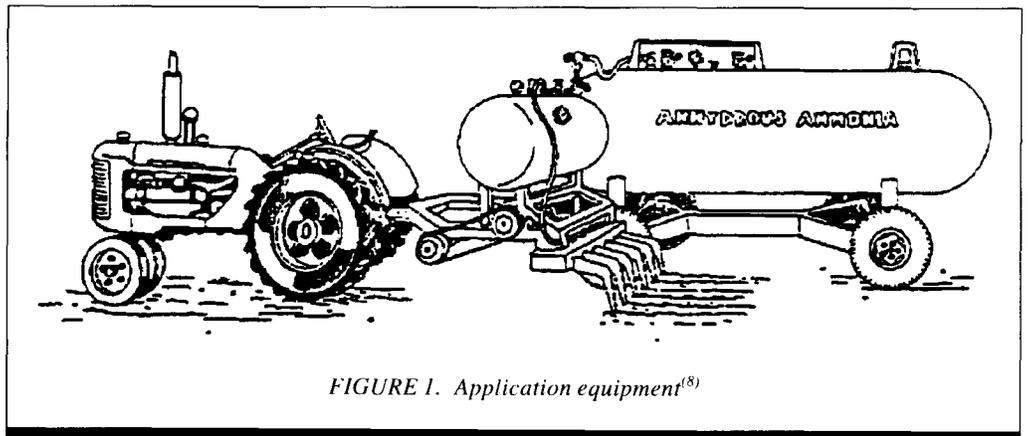


FIGURE 1. Application equipment<sup>(8)</sup>

**TABLE II. HAZOP Guide Word List**

<i>Parameter</i>	<i>Guide Word</i>	<i>Deviation</i>
Flow	No	No Flow
	Reverse	Reverse Flow
	More	More Flow
	Less	Less Flow
	Part Of	Composition
	As Well As	Contamination
Pressure	Other Than	Corrosion/Erosion
	More	More Pressure
Temperature	Less	Less Pressure
	More	High Temperature
Viscosity	Less	Low Temperature
	More	High Viscosity
Level	Less	Low Viscosity
	More	More Level
Abnormal Operation	Less	Less Level
	No	Service Failure
	Part Of	Startup/Shutdown
	As Well As	Maintenance
Ignition	Other Than	Sampling
	No	No Grounding
Relief	As Well As	Relief Capacity
Control Integrity	Other Than	Impaired
Containment/Support	No	Instrumentation
	No	Failure
		Safety Issues
		Environmental Issues

A team of individuals with specific qualifications conducts the HAZOP procedure. The HAZOP is guided by a team leader. HAZOP experience is essential for the team leader but is not a requirement for the rest of the team. It is also essential to include a worker who has everyday operational experience and knowledge specific to the process being evaluated. In OSHA's Process Safety Management regulations, both these individuals must be included; in addition the team members must have expertise in engineering and process operations.<sup>(1)</sup> Using up-to-date equipment and instrumentation drawings and operating procedure descriptions, the process being evaluated is divided into small segments or nodes, such as focussing on a pipe connecting a pump to a storage tank. Possible deviations of the process from normal operating conditions are systematically evaluated by applying a series of guide words to the node. Table II lists some examples of the guide words. The consequences of the process deviations are determined along with the relative likelihood of occurrence. Recommendations for improvements or for more study are made based on the likelihood and severity of the resulting consequences of the deviations. These can be qualitatively determined based on the experience and judgment of the participants, or on available quantitative data, such as "mean time to failure" records.

In addition to evaluating the design of the process equipment, maintenance, operating procedures, and management systems also can be appraised. The results of the HAZOP evaluation are recorded in tabular form for documentation

and subsequent action. Depending on the size and complexity of the system to be evaluated, the actual HAZOP evaluation can be lengthy.

The HAZOP technique was used to identify potential design and work practice problems pertaining to the anhydrous ammonia application operation. The team leader had extensive experience with leading HAZOP evaluations. The two authors were team members who assisted in identifying improvements through design modification. The team also included a representative from a retail anhydrous ammonia distributor, chosen to provide expertise on the retail operations; a representative from an equipment manufacturer, who contributed knowledge about the currently available safety features of the application equipment; an individual from an anhydrous ammonia producer, who provided the team with insights from large-

scale industrial processes and experience in the safe storage and handling of anhydrous ammonia; a state anhydrous ammonia inspector, who contributed knowledge of the routine problems of agricultural anhydrous ammonia storage and application, including regulations and facilities inspections; and a representative from an agricultural trade association, who provided information about the problems encountered in many sectors of anhydrous ammonia application. In addition to providing technical expertise, some participants also were part-time farmers with experience in anhydrous ammonia application.

During the HAZOP evaluation, potential hazards associated with procedures and equipment were identified, as well as potential solutions for reducing this hazard potential. In some cases, it was noted that additional evaluation of the hazard was suggested. The severity and likelihood of the consequences were qualitatively determined based on the experience and judgment of the participants. The HAZOP evaluated the anhydrous ammonia handling from storage at the distributor through the time of field application. This included transfer to smaller tanks, transport of the tanks to the farm, and equipment maintenance.

## RESULTS AND DISCUSSION

This HAZOP evaluation resulted in 95 findings, which can be divided into the following categories: training and

**TABLE III. Sample HAZOP Log Sheet**

<i>Node</i>	<i>Parameter</i>	<i>Guide Word</i>	<i>Possible Causes</i>	<i>Possible Consequences</i>
Node 1: Nurse Tank	Safety	Safety	Emergency water inaccessible	Operator unable to flush away ammonia if exposed
	Corrosion	Corrosion	Use of materials incompatible with additives	Corrosion of relief valves rendering it inoperable. Over pressuring of tank
	Transport	Transport	Unable to stop quickly, untrained driver	Potential for collision resulting in release of ammonia
Node 2: Flexible hose to transfer ammonia to nurse tank	Flow	No Flow	Collapsed or ruptured hose	Hose could fail resulting in liquid ammonia release
Node 3: Toolbar regulator hose from nurse tank to regulator	Flow	Reverse Flow	Disconnect quick connect without first bleeding line	Operator potentially exposed to ammonia
Node 4: Ammonia Storage Tank	Relief		Relief during inspection	Potential injury to inspector
Node 5: Toolbar applicator	Flow	No Flow	Plugged applicator knife	No flow through knife operator could be exposed to ammonia when clearing the pluggage
Node 6: Running gear on field	Flow	Reverse Flow	Quick disconnect failure, improper maintenance	Ammonia hose disconnected from toolbar (in case of quick disconnect failure). Potential to spray operator with ammonia in either case
Node 7: Tank car unloading of liquid ammonia to storage tank	Corrosion	Corrosion	Use of galvanized pipe in place of nongalvanized pipe	Corrosion of line possibly resulting in ammonia release
Node 8: Vapor line from storage tank to tank car, including compressor	Corrosion	Corrosion	Use of copper and brass alloys or other incompatible materials	Corrosion of line possibly resulting in ammonia release

procedures (including operator awareness and knowledge) made up 40% of the findings; equipment design, 31% of the findings; maintenance or inspection, 22%; and material compatibilities, 7%. There are three groups of individuals for which the findings may apply: the farmer, the retail distributor, and the equipment manufacturers. Some of the most important findings will be discussed and presented in Table III. A more detailed summary is available in the HAZOP technical notes.<sup>(5)</sup>

#### ***Findings Related to Training and Procedure***

Most of the findings were concerned with operator training, including hazard awareness, knowledge of the procedures, and good work practices. These training issues would apply to the farmer, the retail distributor, and/or the equipment manufacturer. While many operators are aware of the need for safe handling and the hazards associated with

anhydrous ammonia, all operators should be aware of dangers and how hazardous situations develop. Particular attention to the sequencing of valves was stressed. Untrained personnel should not attempt to stop an inadvertent release of anhydrous ammonia; they should leave the area, notify other persons in danger, and contact the emergency response department. Emergency water should always be accessible to anyone working with anhydrous ammonia. The entry for Node 1 in Table III shows the HAZOP log-sheet entry illustrating this finding.

#### ***Equipment Design Findings***

Some findings suggested the need for research to determine the feasibility and safety of design changes suggested by equipment manufacturers. Other findings suggested reviewing current standards as they applied to design changes.

**TABLE III. Extended**

<i>Actions/Questions/Recommend</i>
A five gallon container of water is to be mounted on tank; multiple sources of emergency water are suggested
All components that may come into contact with anhydrous ammonia or additives must be compatible for that service, even when used for temporary repairs
Towing vehicle should be of adequate size to handle filled anhydrous ammonia tank; driver should be trained
Label ammonia transfer hoses with lot numbers and establish a system to recall defective hoses
Consider designing a weep hole for quick connect coupling
An improved means of stamping relief valves with replacement date should be found
Operator should shut off manual valve in toolbar regulator prior to conducting any maintenance on the toolbar. Appropriate protective gear should be worn
Wear proper safety gear, shut off valves and bleed down both sides of disconnected line, reconnect line. Clean coupler before reconnection
Galvanized pipe is not to be used with anhydrous ammonia, even for temporary repairs
All components that may come into contact with anhydrous ammonia or additives must be compatible for that service, even when used for temporary repairs. Unsuitable materials of construction include, but are not limited to copper and brass components

One change involved the anhydrous ammonia hose. A possible cause of "no flow" through the system during transfer is a hose rupture. This can be caused by damaged or defective hose. According to the participants in the HAZOP, an entire lot of anhydrous ammonia hose can be defective. A finding from the HAZOP was that manufacturers should label the hoses with lot numbers and establish a system to recall defective hoses. Node 2 in Table III illustrates the HAZOP log entry that corresponded to this hazard.

Figure 2a illustrates a suggested design change in the quick disconnect that attaches the applicator-tank hose to the hose on the toolbar. When reviewing the guide word "reverse flow" for the quick-disconnect valve, it was noted that if maintenance is performed without manually bleeding the system, a condition of reverse flow could exist; the pressure could spray anhydrous ammonia on the operator. It was suggested that the feasibility of a weep hole incorporated in this

design should be investigated. Figure 2B illustrates the quick disconnect with the weep hole. The depressurization of the line through the weep hole is inherently safer; maintenance can be performed without direct worker action to depressurize the line. Another benefit is that a temperature increase would not affect the pressure in this hose, therefore avoiding damage to this or other hoses. This HAZOP finding is also an example of a design change that would require an additional study to ensure that no problems are introduced with this suggested design change. See Node 3 in Table III for corresponding HAZOP log entry.

When examining the anhydrous ammonia storage tanks, the state ammonia inspectors noted that the replacement date on the relief valves must be checked during inspections. There is a potential for a burst of ammonia to spray on the inspector as he or she is checking the replacement date. It was suggested that an improved means of stamping relief valves with the replacement date should be implemented to allow for safer inspections. See Node 4 in Table III for this entry.

#### ***Maintenance or Inspection Findings***

Many findings from the HAZOP concerning the farmer involved maintenance and inspection. Based on previous observations, the operator (farmer) generally assumes responsibility for the pre-use inspection of equipment and the minor problems that may occur during application. During the HAZOP, the design of the applicator knives was examined. Under the guide word "no flow," one possible cause of no flow is the plugging of the applicator knives with mud or debris during application. High pressure behind the plug in the knife may force anhydrous ammonia out when the plug is removed by the operator. The finding from the HAZOP is that the operator should shut off the manual valve in the toolbar regulator prior to any maintenance. Appropriate protective gear should be worn. Node 5 in Table III illustrates the HAZOP log entry that corresponded to this hazard.

The connection from the applicator tank to the toolbar also was recognized as a possible high-pressure risk point. Pressure builds up in the hose and during either inadvertent or intentional disconnection may spray the operator when released. The finding from the HAZOP was that the operator should depressurize the system by closing the appropriate valve(s) and bleeding the system before reconnection. Proper safety gear also should be worn. This finding is illustrated in Node 6 in Table III.

Transporting filled anhydrous ammonia tanks from the retail distributor to the farm is often a source of hazard. Sometimes the retail distributor delivers the anhydrous ammonia and application equipment; in many instances, untrained drivers transport the anhydrous ammonia from the retail distributor to the farm. Drivers should receive training pertaining to safe transportation of the filled tanks, including the use of an adequately sized tow vehicle. This finding is in Node 1 in Table III.

#### ***Material Compatibility Findings***

Several findings pertain predominantly to retail distributors and owners of application equipment. As discussed

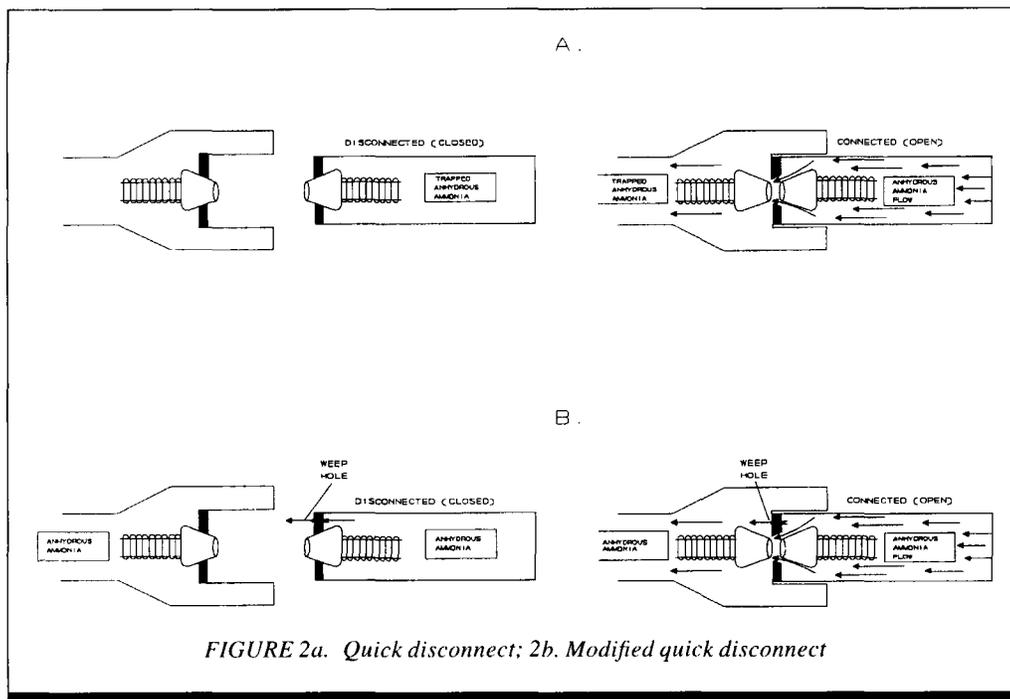


FIGURE 2a. Quick disconnect; 2b. Modified quick disconnect

previously, the maintenance is primarily the responsibility of the retailer distributor or owner of the equipment. It is important that the distributor or owner replace equipment and or components "in kind" (i.e., same material of construction, specifications, etc.) during any maintenance.

Material compatibilities with liquids and other metals must be considered when replacing equipment. Pipe replacement is an example. Occasionally, ammonia inspectors find "temporary repairs" made with galvanized pipe. Galvanized pipe should never be used with anhydrous ammonia as this could result in corrosion of the pipe, thereby causing an ammonia release. Use of copper or brass alloys also may result in corrosion. These two findings are illustrated in Nodes 7 and 8 in Table III.

Relief valves on the anhydrous ammonia nurse tank are made of aluminum. Since a commonly used ammonia additive is incompatible with aluminum, corrosion of the relief valve could result, rendering the valve inoperable. This finding is illustrated in Node 1.

### Application of Findings

This HAZOP study raised many important issues and concerns, and identified potential controls to reduce the likelihood of injury due to agricultural use of anhydrous ammonia. Three groups of individuals that benefit from the findings of the HAZOP are farmers, retail distributors, and equipment manufacturers.

The improvements or changes in procedures will most directly benefit individual farmers. One way to assure that the farmer receives this information is to distribute it through the anhydrous ammonia retailers. In coordination with NIOSH, an agricultural engineering department in a major university has developed an information sheet based on the findings of this HAZOP for distribution to farmers.

The retail distributor will be encouraged to give this sheet to the farmer with each purchase of anhydrous ammonia or rental of anhydrous ammonia application equipment. Also, the distributors often sponsor safety classes for the farmers in their areas. The issues of concern brought up in this study should be incorporated into these classes.

Preliminary results from a farm family survey suggest that farmers commonly turn to farm magazines, veterinarians, medical centers, and the Cooperative Extension Service for information on agricultural health and safety issues.<sup>(6)</sup> These also would be considered as effective media for dissemination.

The results of the HAZOP concerning equipment maintenance and safety plans were summarized in a second information sheet, also developed by the university. These sheets will be incorporated into safety seminars for employees of retail distributors. State anhydrous ammonia inspectors also may be provided with these information sheets to give to the smaller retail distributors.

Findings regarding equipment modification or addition will be communicated directly to equipment manufacturers. Ideally, issues highlighted in this study will help improve the design of equipment and prompt needed research for safer designs.

As with every HAZOP, the results are based only on the experience of the participants. An additional limitation specific to this study is that there were many possible variations of the specific system that was considered. The generic HAZOP presented in this paper must therefore be adapted to make it specific for each site. However, since various aspects of design considered in this evaluation may occur in many facilities, almost every facility can benefit from some aspect of this HAZOP.

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