Methanol Hazards & Safeguards

Lessons Learned From the Global Supply Chain

By Enrique Medina

Methanol is a ubiquitous chemical used in many industrial processes and found in a wide range of consumer goods (Methanol Institute, 2011a). In addition to established uses as a fuel and as a chemical feedstock in the production of formaldehyde or acetic acid to produce consumer goods, methanol is playing a strategic role in emerging technologies for energy sustainability such as hydrogen fuel cells (Crawley, 2007), and renewable biomethanol production to supplement fossil energy sources (Methanol Institute, 2011b). Methanol is also a highly flammable and toxic material whose hazardous properties can easily go unrecognized and result in incidents with substantial human and material impacts. The following incident report is an example of the high severity potential of methanol releases.

On Nov. 16, 2013, a large explosion at the Southern Energy Co. facility in Shelbyville, TN (photo, right), sent one man to the hospital with burns on more than half of his body, destroyed a tanker truck and partially destroyed a chemical storage building (News Channel 5, 2013). According to the news report:

> A tanker truck was trying to transfer methanol into an external storage tank outside the building. In order to take the shipment, they had to draw down methanol in the external storage tank by draining it through plumbing that went inside the building, to a larger vat of methanol inside. The chemist in charge of mixing fuels went inside to operate a pump to begin transferring the fuel. During that process, the internal larger vat may have overflowed, causing methanol vapors to leak into the air. Those vapors then somehow

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IN BRIEF

- **Methanol is a ubiquitous chemical used in many industrial processes and found in a wide range of consumer goods. A doubling of worldwide demand for methanol is projected in the coming decade. Methanol's hazardous properties can easily go unrecognized and result in incidents with substantial human and material impacts.**
- **This article presents a review of the major types and causes of publicly reported methanol-related incidents and describes the most common hazards experienced by methanol users across the global supply chain. Loss of life, serious injury and/or significant material losses can occur when this chemical is not handled properly and with adequate safeguards.**
- **Key elements that must form part of an effective safety management system for methanol users include process safety, corrosion prevention, hot work permits, fire prevention and response, and employee training.**

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ignited, causing the initial explosion at the facility, according to the fire marshal. The fire spread underneath the tanker truck outside, which contained 6,000 gallons of methanol, sparking a secondary explosion that took place after fire trucks had already arrived on scene.

The investigation revealed that the fire department was not aware that the company was operating a biodiesel manufacturing process with methanol in the building, and was looking into possible fire code violations. The injured worker was listed in critical condition at Vanderbilt Medical Center. He was credited with providing first responders critical information about the incident at the scene.

The reported 70 fatalities in the global methanol industry in 16 years may be considered low when compared to other global industries, such as oil and gas production, which reported 88 fatalities in 2012 alone and had sustained more than 80 fatal incidents in 8 of the 9 prior years (IAOGP, 2013). However, a doubling of projected worldwide demand for methanol in the coming decade is driving the expansion of production and storage capacity (IHS, 2013). In addition, new technological processes are moving from experimental to full-scale production.

The growth in demand and new users with limited understanding of the high severity potential of methanol represent an increased risk of incidents in this industry sector. Managing the growth in methanol production will require incorporating risk assessment tools into all new and expanded methanol production, transportation, storage and use operations, and presents a great opportunity to integrate safety-by-design principles into new production technologies.

This article reviews major types and causes of publicly reported methanol-related incidents, (EOS, 2008; Frazier, Barnes & Associates, 2009; Industrial Fire World) and describes the most common hazards experienced by methanol users across the global supply chain. The incidents identified in this article offer valuable insights to risk assessors and managers on the relative likelihood and severity of methanol incidents.

Unfortunately, information on incident precursors, or minor incidents and close calls that occur in countless methanol production, storage and use facilities is not readily available. Nonetheless, these incidents provide valuable lessons learned for methanol safe handling, and enable SH&E professionals to identify effective safeguards and best practices to help reduce the occurrence and magnitude of hazardous incidents. The adage "think globally and act locally" is of particular relevance for safety in the methanol industry.

Methanol Basics

Methanol, also known as methyl or wood alcohol, is a colorless organic liquid at normal temperature and pressure (ACGIH, 2001). Methanol is a product with many useful characteristics that allow it to serve as a fuel or fuel additive, a chemical feedstock, a solvent, a refrigerant and a component in many consumer goods. Recently developed industrial uses of methanol include its application as a denitrification agent in wastewater treatment plants (Methanol Institute, 2011c) to convert water-polluting nitrates and nitrites into nitrogen gas, and as a reagent and solvent in biodiesel production facilities (Penn State, 2008). New applications of methanol are emerging with technological innovations, such as fuel cells for vehicles and consumer electronic products.

Methanol is also a hazardous chemical with significant toxic, flammable and reactive properties that can produce deleterious effects on human health and the environment when not properly handled. The particular hazards of methanol that matter most to particular users depend largely on how methanol is received and stored, how and where it is used, and how much is stored and used at any given time.

Use of methanol requires a controlled environment. Failure to control hazards associated with a small amount of methanol can be problematic with virtually no consequence; loss of control of a large quantity can be catastrophic.

The physical, chemical and biological properties that have major implications in the causes of incidents reported when handling methanol are:

1) Methanol is a flammable liquid that is easily ignited and burns, and sometimes explodes in air. Methanol vapor is marginally denser than air and, depending on the circumstances of a release or spill, methanol liquid will pool and its vapor will dissipate readily from ventilated locations, or it may migrate near the ground and collect in confined spaces and low-lying areas at explosive concentrations. When heated externally, methanol containers are subject to boiling liquid expanding vapor explosion.

2) Methanol is a chemical solvent that is totally miscible in water and retains its flammability even at very dilute solutions. A 75 volume percentage (v%) water and 25 v% methanol solution is considered to be a flammable liquid. Moreover, methanol burns with a nonluminescent flame that may be invisible in bright sunlight. These properties have important implications for firefighting.

3) Methanol is a toxin; ingestion of a small amount (between one and two ounces) may cause death; lesser quantities are known to cause irreversible blindness. Methanol absorbs through the skin and other tissues directly into the blood stream.

A Brief Overview of the Methanol Supply Chain

Methanol Production

Most methanol is produced from natural gas in large integrated chemical manufacturing plants located in regions where hydrocarbon feedstocks are plentiful, such as the Persian Gulf, the Caribbean, South America, Africa and Russia. In China, in particular, most methanol is produced from coal. World production in 2012 reached 61.6 million metric tons (IHS, 2013), and was estimated to reach 64.5 million metric tons in 2013 (MMSA).

Although methanol is used worldwide, the largest consumers use methanol as chemical feedstock in regions that have high industrial development, such as Western Europe, North America and Northeast Asia, which accounted for 80% of imports in 2012 (IHS, 2013). These regions manufacture derivative products: formaldehyde, resins, methyl amines, methyl chlorides, silicones, dimethyl terephthlate, terephthalic acid and methyl methacrylates.

Methanol is amenable to recycling by removing impurities through distillation and introducing the recovered material back into the process. Waste methanol has high caloric value and can be used to recover energy through thermal destructive processes that generate heat to fuel other reactions.

Methanol Transportation

Due to the geographical distance between the major manufacturing centers and the principal users, as much as 80% of the world's annual methanol production is transported between continents by transoceanic shipping. Methanol delivery from the production facility to dockside storage may be by pipeline, barge, rail or truck, and it is pumped from dockside storage tanks into sealed cargo holds of tanker ships. Methanol is received and stored in marine terminals and trans-shipped via truck, rail and barge to chemical production facilities and bulk distributors, where it is stored in tank farms and repackaged into smaller containers. Tanker trucks and trailers complete the distribution network, delivering methanol to the wide range of final users in the methanol supply chain.

Transoceanic transport of methanol is similar to that for other hydrocarbon liquids, such as crude oil, gasoline, diesel and methyl tertiary-butyl ether (MTBE), a fuel additive. Double-hulled vessels are commonly used by shippers, and will likely become the standard as world production increases. Special provisions for tanker shipment are cleanliness to prevent contaminating the methanol; methanol leak detection; appropriate firefighting equipment, including alcohol-resistant foams; and pump, piping, hose and gasket materials that are suitable for methanol service.

Rail transport is considered to be safe, as long as methanol is contained within an upright tanker car. Specially designed tanker cars are equipped with provisions for pressure relief in order to accommodate thermal expansion during transit and short-term sidelining during switching and temporary holding.

Hazards and safeguards relating to rail tank cars apply equally for tankers attached to tractor haul trucks and to tank trailers towed by tractor haul trucks in roadways. Precautions for rail and road transport are much the same as those for ethanol, gasoline, MTBE, jet fuel and distillate, including grounding for protecting against static discharge.

Methanol Storage

Methanol is routinely stored in tank farms consisting of aboveground, floating roof tanks and smaller, internally baffled floating baffle tanks. Storage facilities at docks and marine terminals are typically floating roof tanks, dedicated to methanol handling. Internal floating roofs are preferred to avoid contamination. Facilities must be equipped with leak detection and alarm, as well as appropriate fire suppression and spill response capability (NFPA, 2008).

Tank farms at facilities such as refineries and chemical plants likely have dedicated methanol storage and handling systems. Typically, tanks are aboveground, and piping is aboveground and overhead in pipe racks. Because methanol is commonly stored with other solvents and feedstocks, all piping and valves subject to carrying methanol should be consistently labeled, and direction of flow should be indicated. In general, fire protection for gasoline tanks is sufficient for methanol tanks, provided extra precaution is made for leak detection, toxic hazard and availability of alcohol compatible fire suppression foam. Tanks must be grounded to avoid hazards associated with static discharge (NFPA, 2008). Ignition control may be by nitrogen padding, natural gas padding or by designation of a hazard zone with ignition control.

Although common, tote and drum storage of methanol can be problematic. Unlike tank farms, where personnel seldom have direct contact with methanol, users of totes and drums typically experience spillage that requires immediate response and subsequent cleanup.

Storage of methanol is subject to substantially the same provisions as those used for gasoline storage. All storage materials, including totes and drums, require berming and adequate ventilation. Berming should be stabilized by compacting, by use of suitable methanol resistant fabric or with concrete. Because of the solvent properties of methanol, asphalt and road oil are not suitable as berm cover/stabilization materials.

The particular hazards of methanol that matter most to particular users depend largely on how methanol is received and stored, how it is used, where it is used, and how much is stored and used at any given time.

Health Hazards of Methanol Exposure

Methanol's primary routes of entry into the body are by inhalation, absorption through the skin as a result of contact, eye contact, and ingestion by either eating or drinking.

Humans are exposed to methanol from many sources. Food is the primary source of exposure for the general population. Methanol is widely found in small concentrations in the human diet from fresh fruits, vegetables and commercial beverages such as fruit juices, beers, wines and distilled spirits (IPCS, 1997).

Occupational exposure is likely to cause the highest daily exposure to methanol. Occupational exposures typically occur through inhalation of methanol vapors during production or use. About 70% of the methanol produced in the U.S. is used as feedstock for the production of other organic chemicals and various consumer products, including windshield washer fluid. According to OSHA 29 CFR 1910.1000, Toxic and Hazardous Substances, the time-weighted-average (TWA) permissible exposure limit (PEL) to methanol is 200 ppm for an 8-hour day and 40-hour work week.

Methanol is a poison. It can cause severe and sometimes fatal acute toxic effects from a single exposure through any primary route of entry. Methanol irritates the eyes, skin and upper respiratory tract. Eye exposure can cause a burning sensation accompanied by tearing, redness and swelling. Direct contact with the liquid may cause conjunctivitis and corneal burns. Methanol removes oils from the skin and causes it to become dry and cracked.

Signs and symptoms of methanol poisoning include headache, dizziness, vomiting, severe abdominal pain, back pain, difficulty breathing, cold extremities, lethargy and lack of coordination. At times, high doses may result in blindness or death (ACGIH, 2001). The signs and symptoms of methanol exposure do not occur immediately. The time lag between exposure and onset of symptoms may lead to misdiagnosis of the cause, particularly in persons who are unaware that they have been exposed, unaware of the toxic nature of methanol, or unaware of the differences between methanol, ethanol and isopropyl alcohol.

A very small amount of methanol can cause acute methanol exposure with severe consequences: Assuming that 100% methanol fuel is swallowed, the lethal dose is less than 1 teaspoonful (4 ml) for a 1-year-old infant, 1.5 teaspoons (6 ml) for a 3-year-old child, and less than 2 tablespoons (28 ml) for an adult (IPCS, 1997).

Review of Methanol Incidents

Many major incidents of methanol spills, fires and explosions have been reported in the international media, and compilations of private reports and public agencies are available on the Internet. However, a comprehensive list of incidents involving methanol that have occurred throughout the global supply chain is not available in a centralized database at this time. The widespread uses of methanol from solvents to alternative fuels make this a complex task.

Table 1 presents incident data compiled from Internet research covering 1998 to 2013 and includes incidents reported in the U.S., Canada, Brazil, France, Italy, Germany, Sweden, China, India, Malaysia, Spain, South Africa and Australia. The complete list of incidents on which this table is based is included in the reference section.

This table is not intended to be a complete or representative statistic of the relative frequency or magnitude of such incidents. However, it can serve as a point of departure to evaluate the common types of incidents involving methanol and to help readers identify the risks and develop safety measures to prevent potential disasters.

Of the 92 separate incidents involving methanol reported from 1998 to 2013, fires or explosions account for 83% of all incidents, and spills represent 12% of the total. Industrial methanol users, including biodiesel manufacturers plus the transportation sector, together account for six out of every seven incidents reported, and 96% of all fatalities.

The industrial sector, which includes biodiesel production, was the top category responsible for most methanol incidents, accounting for 58% of all cases. Biodiesel manufacturing itself represents nearly half of the 53 industrial incidents, with 25 fires and/or explosions. Most of the other industrial cases also involved fires or explosions, plus two reported spills and one vapor release.

Of the 26 incidents in the transportation sector, which accounted for 29% of all cases, 10 involved road transport and as many were railway related. Six shipping incidents were reported as well. Sixteen of the 26 incidents resulted in a fire or explosion, six caused spills, and the remaining four resulted from collisions, rollovers, derailments and ships running aground with no significant loss of material.

Table 2 shows the rates of injuries and fatalities caused by the methanol-related incidents reported in this review. Transportation-related incidents accounted for the highest number of casualties, with

Table 1

Types of Methanol-Related Incidents by User Sector, 1998-2013

Sector	Total incidents	% of incidents	Fire/explosion incidents	Spill incidents	Other incidents
Biodiesel	25	27%	25	0	0
Industrial	28	31%	25	2	1
Transportation	26	29%	16	6	4
Home	4	4%	4	0	0
Pipelines	4	4%	1	3	0
Schools	3	3%	3	0	0
Commercial	1	1%	1	0	0
Water treatment	1	1%	1	0	0
Total	**92**	**---**	**76**	**11**	**5**
Percentage	**100%**	**100%**	**83%**	**12%**	**5%**

Table 2

Methanol Incident Fatalities & Injuries by User Sector, 1998-2012

Sector	Incidents	Fatalities	Injuries	% of fatalities	% of injuries
Transportation	26	57	10	81%	17%
Industrial	28	6	23	9%	39%
Biodiesel	25	4	7	6%	12%
Water treatment	1	2	1	3%	1.5%
Commercial	1	1	1	1%	1.5%
Schools	3	0	12	0%	20%
Home	4	0	5	0%	9%
Pipelines	4	0	0	0%	0%
Total	**92**	**70**	**59**	**100%**	**100%**

81% of all fatalities and 17% of all injuries. Half of the transportation fatalities resulted from a 2012 collision between a methanol-carrying tanker truck and a passenger bus in Yan'an, China, which left 36 people dead.

Industrial incidents excluding biodiesel had the highest number of nonfatal injuries, involving 23 people, as well as six fatalities. The biodiesel industry accounted for four deaths and seven injured workers. Injuries reported for homes and school incidents were due to burns. No fatalities were reported in home, school or pipeline incidents.

The highest severity incidents reported other than in transportation occurred during maintenance-related hot work on methanol tanks. A welding incident in a Kuala Lumpur, Malaysia, chemical plant killed three workers and severely injured a fourth. A welding incident at a wastewater treatment plant in Daytona Beach, FL, resulted in two deaths and one injured worker. The incident was investigated by CSB. The following excerpt from its report illustrates the dangers of hot work:

> On Wednesday, Jan. 11, 2006, three workers were removing the shed roof of a chemical tank farm. About 11:15 a.m., the lead mechanic and one worker were on a man-lift basket cutting the metal roof directly above the methanol tank vent. A mechanic was operating a crane to hold the roof sections as they were being removed. Sparks, showering down from the cutting torch, ignited methanol vapors coming from the vent, creating a fireball on top of the tank.
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> The fire flashed through a flame arrester on the vent, igniting methanol vapors and air inside the tank, causing an explosion inside the steel tank. Methanol discharged from the separated pipes ignited and burned, spreading the fire. Methanol also flowed into the containment around the tank and through a drain to the wastewater treatment plant where it was diluted and harmlessly processed.
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> The lead mechanic and the worker in the man-lift basket were likely burned from the initial fireball and burning methanol vapors discharging from the tank vent under pressure from the explosion. The lead mechanic, fully engulfed in fire, likely jumped or fell from the man-lift. Emergency responders found his body within the concrete containment next to the tank. The worker stated that he had been partially out of the man-lift basket leaning over the roof when the fire ignited. On fire, he climbed onto the roof to escape. Coworkers, unable to reach him with a ladder, told him to jump to an adjacent lower roof and then to the ground. He sustained second- and third-degree burns over most of his body, and was hospitalized for 4 months before being released to a medical rehabilitation facility. Methanol sprayed from separated pipes onto the crane, burning the crane cab with the mechanic inside. On fire, he exited the cab and was assisted by coworkers. He died in the hospital the following day. (CSB, 2007)

The investigation identified the incident's root and contributing causes:

•The city did not implement adequate controls for hot work and had an ineffective HazCom program.

•The methanol system design firm approved using PVC instead of steel piping in the tank; approved the use of an aluminum flame arrester, which is not compatible with methanol use; and did not require preventive maintenance of the flame arrester.

Fatalities due to poisonings from the illegal use of methanol in alcoholic beverages are not included in this analysis. Nonetheless, 61 homeless people died after drinking methanol-laced beverages in one incident reported in Khartoum, Sudan, on June 24, 2011 (*Sudan Tribune,* 2011). This horrific fatality count was only slightly less than the total fatalities from all of the incidents reported in Tables 1 and 2 over a 15-year period.

The time lag between exposure and onset of symptoms may lead to misdiagnosis of the cause, particularly in persons who are unaware that they have been exposed or are unaware of the toxic nature of methanol.

Common Causes of Incidents

It is not always possible to determine root causes of the incidents reported by the media or in the compiled reports. Almost one-third of the incidents reported have an unknown cause. Another 10%, or nine cases, can be categorized as nonintended uses involving children and adults playing with methanol and fire, or school science class experiments gone awry.

Routine Operations & Maintenance

In the industrial and biodiesel sector, routine operations such as mixing materials, reactions involving high temperatures or pressures, and material transfer operations seem to account for more than half of fire or explosion incidents where an activity was recorded. It was not possible to identify the specific work activity in one-third of all industrial cases. Biodiesel manufacturing accounts for two-thirds of all industrial incidents reported with known causes.

Maintenance-related issues appear to account for 45% of the incidents with known activities. Hot work involving welding or grinding on methanol storage tanks or containers represents half of the maintenance incidents. Faulty electrical installations, and failures of equipment, transfer lines, pumps or safety valves account for the remaining 55%.

Transportation Activities

In the transportation sector, collisions, derailments and other moving incidents by auto transport, railcars, or ships and barges account for more than three-quarters of all of the incidents with known causes.

Transportation incidents appear to have occurred during routine operations while the vehicles or vessels carrying methanol were on the road, on rail or underway in marine waters. Only three incidents could be directly attributed to maintenance issues. Information on the proximate causes of the remaining incidents was not available. Interestingly, there are no reported cases of spills during material transfer operations. All transportation spills reported are due to collisions, derailments or rollovers, with one incident of a minor spill in a storage rail yard.

Pipeline Incidents

Of the four reported pipeline incidents (three spills and one fire), one occurred during standard operations and three occurred during routine maintenance activities.

Key Findings

The incident statistics show that while fire and explosion, often resulting from a spill or other release, are the most common outcomes of methanol incidents, their causes can vary depending on the activity being conducted. Transportation incidents, whether on road, rail or water, seem to occur during routine activities. Pipeline incidents are associated with equipment maintenance, while industrial and biodiesel production incidents in particular appear to be evenly distributed between maintenance and routine operations.

One common factor shared by all is the human element. Human reliability is a management responsibility, and is of key importance in evaluating the consequences of these incidents. This underlines the critical importance of understanding the hazards of methanol and of learning and practicing the procedures for safe handling and responding to emergency situations.

While it is not possible to identify the relative contributions of place, people and process that resulted in each event, we can benefit from lessons learned in incident analysis and process safety management of similar industries and processes. Common factors that contributed to methanol-related incidents are the following:

- insufficient understanding of methanol's physical, chemical and flammable properties;
- methanol container, hose or pipeline integrity not preserved;
- accumulation or release of methanol vapors in flammable concentrations;
- inadequate spill containment capability;
- obvious ignition sources, such as hot work, not recognized or controlled;
- ignition sources such as static electricity, electric arc from nonexplosion-proof equipment or installations, friction and mechanical sparks, or exothermic chemical reactions not identified or difficult to control;
- inadequate equipment maintenance;
- standard operating procedures for routine operations not followed or inadequate;
- process safety measures not in place or not followed;
- fire prevention systems not in place, inadequate or not operational;
- inadequate emergency response planning, training, equipment and/or supervision;
- failure to recognize the magnitude of the hazard or developing event, and to take appropriate and timely life safety protection measures.

Recommended Safeguards

To reduce the probability and consequences of a catastrophic incident, methanol users must have the right tools to help them recognize the particular hazards of the type of operation or activity they are involved in and to identify the appropriate safeguards to control those hazards. In the chemical industry, this is best achieved through a safety management system composed of three elements: people, equipment and procedures. One key concept of the systems approach is to realize that if anything changes in the system, it effectively changes the system. These changes may allow previously unrecognized unsafe or hazardous situations to arise and result in a mishap.

All effective systems require proper planning, operator training and implementation. The procedures must be complete, written, regularly updated and rigorously followed. The process must have the proper equipment for methanol service, such as nonsparking tools, intrinsically safe electrical equipment, and proper material selection for vessels, piping, seals and flanges to prevent corrosion and reduce chemical degradation. The equipment must be properly maintained and documented, and workers must be properly trained in the procedures and the equipment and supervised to perform their jobs safely and effectively.

Following are the key elements that must form part of an effective safety management system for methanol users. These elements may be scaled to the appropriate level depending on the type of operation, storage or throughput volume and conditions in which methanol is handled.

Process Safety Management

Process safety management (PSM) is one safety management system that has been in effect in the chemical industry for more than 20 years (OSHA, 1992). In the U.S., most facilities that store, process or use 10,000 lb (1,508 gallons) or more of methanol are required by OSHA to implement PSM. The intent of PSM is to know, understand and control hazards of chemicals, process technology and equipment used in large and small chemical operations and activities.

PSM consists of 14 management elements that work together in a synergistic and systematic fashion. Each element addresses a particular aspect of the process necessary to safely manage chemical hazards. However, the elements can be scaled to the specific facility and implemented by all facilities as needed. Other models of chemical process safety in use around the world can be effectively adopted by methanol users as well.

Process hazard analysis (PHA) is one key PSM element. PHAs are conducted periodically to verify that sufficient safeguards are in place to protect against abnormal operating conditions and to avoid accidental release of process materials to the workplace, adjacent communities and the environment. Various methodologies are available, ranging from what-if assessment, involving a group of persons familiar with the circumstance, to hazard and operability study for high-hazard operations such as transportation and biodiesel, and up to a rigorously structured quantitative layers of protection analysis or fault-tree analysis for more complex systems, such as methanol production facilities, refineries, and major storage and distribution terminals. Projects with significant capital costs and dependent on global conditions integrate risk assessment, reliability analysis and return on investment to properly evaluate and mitigate the interconnected safety, operational and financial risks.

Corrosion Prevention

Focusing on methanol's flammability can obscure the hazards posed by its corrosive properties. Liquid methanol is electrically conductive compared to natural gas and distilled fuels (Methanol Institute, 2013). As a result, containers holding methanol are more susceptible to galvanic corrosion than are containers holding hydrocarbons such as gasoline. Fluid conductivity increases corrosion of alloys commonly used to handle natural gas and distillate fuel, particularly aluminum and titanium alloys.

Addition of methanol to a hydrocarbon can serve either of two intents: to dry wet hydrocarbon or to enhance hydrocarbon fuel properties. Methanol is routinely added to water-contaminated hydrocarbons, such as propane, to improve combustibility by solubilizing the separate water phase into a single hydrocarbon-methanol-water phase. In the case of methanol-hydrocarbon-blended fuels, however, if excessive water is present, it extracts methanol from the hydrocarbon-methanol blend and forms a dense methanol-water phase separate from the hydrocarbon phase. The dense methanol-water phase concentrates water-soluble corrosion agents such as chlorides, thereby increasing the probability and accelerating the rate of localized corrosion damage. Even in the absence of chlorides, the water phase promotes generalized corrosion of metal alloys.

Additionally, methanol is a solvent and is compatible with only selected plastics and rubbers (Plastics Pipe Institute, 2007). Plastic containers commonly used for gasoline may lose structural integrity when used to hold methanol and must be replaced with more corrosion- and solvent-resistant materials. Storage containers and pipeline conveyance systems should not be used in methanol or methanol vapor service without a rigorous mechanical integrity and fitness for service program in order to reduce the risks of leaks and spills, which are often the precursors of fires and explosions.

Hot Work Permit Program

The hazards associated with hot work can be reduced by implementing an effective hot work permit program. This should include prior work authorization, safe welding practices and a fire watch.

Fire Prevention & Response

The three key aspects of fire response are early detection, immediate response and appropriate action. While the particular application of these principles may vary, a well-planned and -developed system depends on training, equipment and practice.

Employee Training

The employer must inform all employees of the safety and health hazards of methanol and train them how to effectively control those hazards and associated risks. The information reviewed here shows that incidents can occur because the individuals handling methanol or performing work near methanol storage and handling areas are unaware of the risks. These incidents are an indication that the safety management system has not assigned the appropriate level of resources to properly train and supervise employees.

Operating personnel must be trained in interpreting and applying the written operating procedures, as well as those for upset conditions and emergency response. As a practical matter, training must include both classroom and on-the-job training, supplemented by drills and simulations that may include complete mock events or tabletop exercises.

Training is a dynamic process that must be refreshed on a regular basis. Effective training involves initial training upon assignment, periodic refresher training and update training. Update training is critical and should be done whenever a change is made in the process or when an incident or near-miss occurs.

Effective training and skills development must be conducted in a manner and at a level that is clearly understood by all workers, and must include evaluation tools that demonstrate a minimum level of understanding and skills proficiency. A thorough understanding of how methanol's physical and chemical properties affect flammability hazards and severity is an essential training topic for all methanol workers.

Conclusion

This analysis of historical incidents demonstrates that the hazards inherent in the use, storage and transportation of methanol can result in serious and catastrophic events. Loss of life, serious injury and/or significant material losses can occur when this chemical is not handled properly and with adequate safeguards. The following conclusions are based on information gathered from these incidents:

- Conditions conducive to catastrophic events exist in all phases of the methanol supply chain, including the manufacture, transportation, distribution, storage and processing sectors, as well as in educational, recreational and residential settings.
- Serious incidents from methanol use, transportation or storage can and do occur in large and small operations, and in operations that have widely differing levels of technical capability.
- Emergency response and spill prevention capabilities, training and equipment are essential elements of safe methanol handling. Many spills result in fires and explosions.
- Most incidents and many fatalities could have been prevented by implementing proper hot work permit procedures prior to welding or grinding activities.
- Mechanical integrity (fitness for service) and proper predictive, preventive and corrective main-

Handling Guidelines

The incidents reviewed in this article are examples of gaps in the safety systems in place that allowed potential risks to manifest as fatalities, injuries and financial losses. Additional information on the hazards, risks and safeguards of methanol production, transportation, storage and use can be found in the *Methanol Safe Handling Manual* produced by the Methanol Institute free of charge and available in English, Arabic, Chinese, Spanish and Japanese, to address both common and technical questions related to methanol handling, storage and transportation throughout the global methanol supply chain. Find the guide at **http://bit.ly/1nPn67L**.

tenance of equipment for methanol service is of key importance for all methanol users.

•Understanding the importance of corrosion causes and prevention in methanol service conveyance systems, pipelines and storage tanks is essential. This is of particular importance in marine terminals, tank farms, chemical plants, loading racks and for all industrial users that inventory large volumes of methanol.

•Recognition, identification and control of potential ignition sources must be emphasized in all situations in which methanol is present and releases are possible. This should include sources of heat, fire, friction, electrical arc, static electricity, sparks, chemical reactions and physical process conditions, among others.

•Industrial methanol users, and the biodiesel manufacturing industry in particular, will benefit from implementing process safety management practices and procedures for routine and special operations as well as emergency conditions.

•Operator training in the physical, chemical and flammable properties of methanol is an essential element in safe handling, in particular for industrial and transportation workers. **PS**

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Additional Resources

To view additional information about the CSB investigation of the methanol explosion at the Bethune Point facility in Daytona Beach, FL, visit **http://bit.ly/1hNXlQq**. This link will take you to ASSE's Body of Knowledge (BOK), where you will find a video from CSB that describes the investigation findings, as well as links to the investigation report. Once in the BOK, enter the search term "methanol" to access several additional links, including a NIOSH Fatality Assessment and Control Evaluation report on a fatal incident in Michigan.