Best Practices in Prevention and Suppression of Metal Packing Fires

August 2003

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Summary

Metal structured packing fires present a unique hazard. When packed columns are opened to the atmosphere, structured packing can ignite if the proper conditions are present. Factors which increase the likelihood of packing ignition include the presence of residual flammable organics on the packing, the presence of pyrophoric substances, and hot work conducted inside the column. Since a packed column fire can result in the loss of millions of dollars and the loss of human life, it is prudent to follow industry best practices with regard to design and maintenance of packed columns and to follow proper procedures in the suppression of packed column fires.

A properly designed packed column should be sited near a fire water source and should allow for easy access of personnel in the event of a fire. Also, packing should be made from the least reactive material that would be suitable for the operating conditions. Titanium should be avoided when possible.

During maintenance, work crews should be alerted to the possibility of packing ignition. Shutdown should be properly planned and documented, and the column must be cleaned thoroughly and cleared of flammable or pyrophoric materials prior to entry. The conditions inside of the column should be monitored and personnel must be ready to respond immediately if a fire is detected. Finally, special precautions should be taken if hot work is to be conducted inside the column. Precautions include the use of physical barriers to prevent sparks from contacting the packed bed and procedures to prevent packing ignition or to extinguish rapidly any fires that could ignite. The best practice for preventing packing ignition during hot work is removal of the packing prior to maintenance.

Metal packing fires should be extinguished with extremely large amounts of water as soon as a fire develops. Explosions may result if water is provided in insufficient quantities. If a fire is not extinguished before it can spread through the packed bed, it is likely that it will have to burn itself out, resulting in major loss of property.

While this information is state-of-the-art in best practices, needs for additional packed column research and technology are identified for combustion characteristics of packing materials, development of new materials, ignition sources, fire suppressants, and column designs.

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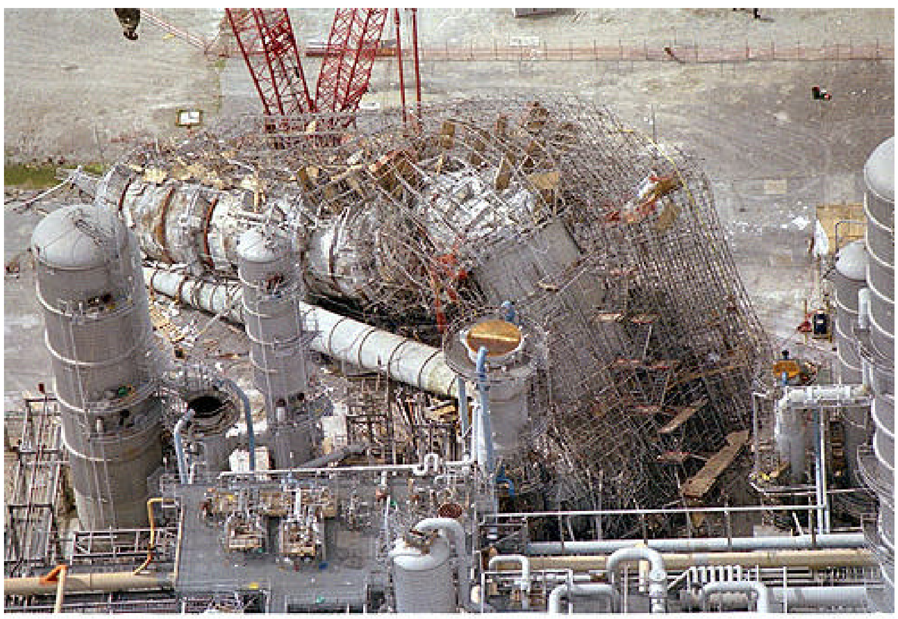
Introduction

The use of metal structured packing in industrial mass transfer applications is expanding. This popularity is due to the high surface-to-volume ratio of structured packing, which allows for higher efficiency and capacity than can be achieved with random packing or trays (Kister, 1992). Unfortunately, the features that make structured packing superior in many applications also make it a combustion hazard.

One incident involving structured packing occurred in a 250 ft tall, 30 ft diameter distillation column during a shutdown. The column was cleaned and inspected, and contractors began work on the column two days after it was shut down. Two days later, smoke and glowing were observed in the packed bed inside the column, which was evacuated without injury. Fire crews worked to extinguish the fire but were unable to

Figure 1: Collapsed Distillation Column (Holliday, 2002)



accomplish this, and the column collapsed eight hours after the fire was noticed (Holliday, 2002). A photograph of the collapsed column is shown in Figure 1.

One manufacturer of structured packing has identified at least 56 incidents of structured packing fires, though more column fires probably occur than are reported. No fatalities have been reported, but a column fire can lead to destruction of a column and days to months of lost production time, which can result in millions of dollars in losses.

In order to prevent further incidents, possible mechanisms for ignition of packed beds and flame propagation within packed columns should be well understood, and best practices should be followed for column design and maintenance procedures to prevent such incidents. Furthermore, proper techniques for extinguishing metal fires should be utilized.

Ignition of Packed Beds

It is a common misconception that metal cannot ignite. This statement may be true for large sections of metal with a relatively small surface to volume ratio like metal slabs or pipes, but thin metal sections and metal dusts can ignite, given oxygen and an ignition source, especially if there are flammable materials coating the surface. The following ignition sources have been identified that could ignite a packed bed:

1. **Ignition by Pyrophoric Compounds -** Pyrophoric materials on a bed of structured packing can ignite upon exposure to atmospheric oxygen during a column shutdown. Pyrophoric materials can include inorganic compounds such as FeS (Sahdev, 2002) or organic dusts or films. Column fires have also been ignited by compounds that were not previously known to exhibit pyrophoric behavior.
2. **Hot Work -** Hot work inside a column can shower sparks or molten slag down onto a packed bed. This may ignite the packing itself or may ignite combustible materials on the packed bed which can then ignite the packing.
3. **Combustion of Flammable Deposits or Films -** Flammable materials on the packing or lodged inside the packed bed can ignite the structured packing if they catch on fire. It is often difficult to tell whether or not a packed bed is completely free of any flammable material.
4. **Exposure to Oxidizing Environments-** Some types of packing material can be ignited by strong oxidizers. An example is the combustion of titanium upon exposure to red fuming nitric acid (RFNA) (Bomberger, 1987).
5. **Static Electricity-** It is possible for static electricity to ignite fine dusts inside a packed column that could ignite a packed bed (Wagner, 2002).

The exact mechanism for the ignition of structured packing is not very well characterized, and the flammability characteristics of packing materials are not well understood. Therefore, it is a good practice to assume that any packed column that is open to the atmosphere can present a combustion hazard, particularly if the process fluid is flammable or forms combustible fouling products.

Factors which Enhance Combustibility

Several factors can make structured packing more likely to ignite. One factor that can increase the likelihood of a metal fire is the presence of dusts or finely divided material in a packed bed. Dusts can accumulate in a packed bed as a result of corrosion of the metal packing or the accumulation of fouling deposits or other solid particles entrained in a process fluid. At least one incident involved the ignition and combustion of fines that accumulated in a column as a result of packing corrosion. Dusts can be a problem when packing is made from titanium due to the relatively low ignition temperature (625°F for a cloud of titanium dust or 1000°F for a layer of dust) of titanium corrosion products or titanium dusts (Jacobson, 1964).

Additionally, packing material can influence the combustibility of packing. For example, titanium, which is classified as a reactive metal, may be more susceptible to ignition than carbon steel or stainless steel packing. In one incident involving the ignition of titanium packing, workers ignited the packed bed by grinding on the packing to identify the packing material in accordance with the National Fire Prevention Association (NFPA) guidelines (found in NFPA 481, Appendix B). The titanium sparks incited a thermite reaction, which resulted in extensive damage to the packing. The fire also burned a six inch hole in the bottom of the vessel (Mary Kay O'Connor, 2002). Additionally, titanium fires cannot be extinguished by flooding a column with nitrogen (Pelekh, 1999). Materials selection should be a significant a factor in packing design, particularly where there is a known risk of packing ignition.

Additionally, thermite reactions[1] can lead to packing combustion. A thermite reaction is the highly exothermic reaction of a metal with a transition metal oxide. Both aluminum and titanium can participate in thermite reactions, which can be incited by an external ignition source. Since thermite reactions burn at temperatures as high as 5400°F (Geyer, 2002), a thermite reaction can ignite surrounding packing, as with the incident described in the above paragraph.

Finally, flammable materials lodged in the packing or present as films on the packing surface can increase the probability of packing ignition. Examples of combustable materials that can be present on packing include oil from packing construction (in the case of new packing), flammable polymer deposits, or unwanted pyrophoric materials formed in the process. One example of a pyrophoric deposit that has been responsible for column fires is FeS, which forms in refinery process streams from the reaction of H_2S with steel. FeS deposits are pyrophoric, and can accumulate in column packing and ignite when a column is open to oxygen if the deposits are not properly removed (Sahdev, 2002).

Best Practices in Design

In order to minimize the risk of packing ignition and prevent a catastrophic loss of a column fire, it is important that columns containing structured packing be designed with safety in mind. The risk of a major loss due to a column fire can be minimized through siting of the column, vessel design, packing selection, and planning procedures to extinguish a fire.

Vessel Design and Siting

A packed column should be sited so that adequate firewater is available. Ideally, firewater should be able to reach the top of the column without a booster pump. Additionally, a packed column should be sited so that fire crews can get to a column quickly, since a fully developed metal fire is nearly impossible to extinguish. The column vessel should have large manways (30" or greater) to allow for removal of structured packing. Also, the packed column should be marked as containing structured packing and vessel markings should refer to procedures for opening the column and conducting maintenance.

Packing Materials Selection

The possibility of a column fire should be considered in packing selection, particularly where operational factors increase the risk of a column fire (such as fouling or highly flammable process materials). In cases where packing fires have occurred in columns similar to the one under design, it may be prudent to install trays or plastic random packing if this is possible. Material compatibility should also be considered in packing selection to prevent combustible corrosion products or packing fines from forming inside the packed bed. The installation of titanium structured packing should be avoided, if possible, in services where process conditions may create a flammable atmosphere inside the column when the column is opened or where titanium packing has proven to be a hazard.

How Packing Design Affects Flammability

The flammability of structured packing is directly proportional to its surface-to-volume ratio. Wire gauze packing has the highest surface-to-volume ratio of all types of structured packing and is therefore the most combustible type of packing available. An increased surface-to-volume ratio can also cause packing to burn

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[1]Thermite Reaction
Thermite is a mixture of aluminum powder and iron oxide, Fe_2O_3. When the mixture is ignited, iron oxide is reduced in a highly exothermic reaction to form aluminum oxide and molten iron, as follows:

$$2Al + Fe_2O_3 = Al_2O_3 + 2Fe$$

more quickly and more intensely, based on research conducted on aluminum powders in oxygen-enriched environments (Dunbobbin, 1991).

Two factors that affect the surface-to-volume ratio are the spacing between packing sheets and the thickness of the sheets that make up the packing. Increasing the size of the spaces between sheets of packing in a packed bed allows the oxygen in the atmosphere to be more available to the metal and increases flammability (Dunbobbin, 1991). Increasing the void space, however, decreases solids fouling of the packing (Kister, 1994). This means that for services where pyrophoric solids are an issue, a larger channel size may decrease the likelihood of ignition by decreasing the tendency for pyrophoric materials to become lodged in the packing. Decreasing the thickness of the packing sheets increases flammability by allowing the flames to propagate through the packing more quickly (Yeh, 1997).

While increasing the surface-to-volume ratio increases the flammability of structured packing, it also increases efficiency, since it increases the degree of vapor-liquid contact per unit height of the packing. Increasing the size of the spaces between the sheets (channel size) of the packing decreases efficiency, but increases its ability to tolerate fouling due to solids and increases the packing capacity (Kister, 1994). Because of these factors, trade-offs must be made between safety and efficiency in packed column design.

Best Practices in Maintenance

Most metal fire incidents in industry have occurred during maintenance because the column is open to the atmosphere and maintenance often involves hot work on the column. All of the incidents discussed in this document occurred during maintenance and could have been prevented if proper precautions had been taken.

A plan for shutdown, cleaning, and procedures during maintenance should be prepared before opening a packed column to the atmosphere. The column should be properly cleaned and care should be taken when exposing the vessel internals to the atmosphere. If hot work is to be conducted inside the column, physical and procedural barriers to packing ignition should be installed.

Pre-shutdown planning

The first step during a column shutdown should be to determine whether or not the packing can be safely removed from the column before mechanical or hot work begins inside the vessel. Removing the packing from the vessel is the best way to ensure that the packing does not ignite during maintenance. If the packing can be removed from the column, enough time should be scheduled for the column shutdown to remove and replace the packing in the tower. A shutdown plan prepared in advance should ensure that all responsible parties (including engineering, operations, and maintenance) be aware of potential fire hazards associated with metal packing. The plan should also include provision for the following:

- Clear documentation of potential hazards associated with the vessel to be opened.
- Procedures for proper column shutdown and cleaning.
- Plans for the placement of proper physical barriers, including water barriers or fire blankets, to ensure that hot work inside the vessel does not ignite the column packing.
- A plan for monitoring the carbon monoxide levels and temperature of the column during shutdown so that fires can be easily detected in their early stages.
- Assurance that fire-extinguishing mechanisms are in place and that the area around the column is clear so that fire crews have easy access.

- Clear documentation of the expected conditions inside the vessel and a statement that all work will be stopped and the plan reevaluated if conditions other than those expected are found.

Prior to shutdown, work permits should be double-checked to ensure that they are properly signed and that the permits cite the proper requirements for carrying out the inspection and maintenance activities in and around the column. Finally, contingency plans should be ready for implementation in the event of an incident, and the appropriate fire crews (either local fire department or plant fire department, whichever is appropriate) should be informed of the potential risk of a metal fire.

Cleaning the Column Internals

Before a column is opened and the packing is exposed to oxygen, it is important to ensure that the column internals are as clean as possible. One manufacturer of packed column internals recommends the following practices during column cleaning to reduce the risk of a packing fire due to pyrophoric deposits when the vessel is open:

1. Follow normal shutdown procedures for cleaning the column. Dry (superheated) steam should be used to prevent damage to the packing that may result if wet steam is used due to condensation and rapid evaporation that may take place inside the packed bed.
2. Allow the column to cool below 212°F. Compensate for any volume contraction during cooling by adding nitrogen to prevent a vacuum from forming in the column.
3. Continue cooling of the column, ensuring that all sections of the column are adequately supplied with water. Monitor the column temperature and continue cooling the column for at least 24 hours and until the temperature inside of the column is less than 100°F.

Additionally, chemicals may be used to remove pyrophoric deposits from the column internals. For example, refiners routinely use oxidizers like potassium permanganate to remove pyrophoric FeS deposits from the inside crude distillation units. Care must be taken, however, to ensure that chemicals used to clean the column do not present a significant environmental, health, or explosion hazard (Sahdev, 2002).

Opening the column for maintenance

Industrial sources recommend the following practices to ensure that packing does not ignite after opening and that proper measures are in place prior to hot work on the column:

- Keep vessel internals wet to the extent possible. Flooding the vessel to the top of the packed bed prior to opening the column is an option if the vessel will not be damaged under the hydrostatic load. Care should be taken to ensure that flooding the vessel will not cause any additional environmental or safety concerns.
- The column should be properly blinded, and manways should be opened from top to bottom. Allow a sufficient time interval between each manway opening and after each column section has been checked for high temperature and the presence of organic vapors. One to two hours is a generally recommended interval.
- A minimum number of manways should be opened and unobstructed to allow for easy shut-off of the column in the event of a fire.
- Temperature and carbon monoxide levels should be monitored throughout the column shutdown to ensure early detection of metal fires. Fully developed metal fires are nearly impossible to extinguish, so special attention must be given to suppressing metal fires in the early stages. All instruments to

monitor these levels throughout the column shutdown should be in place before hot work is started within the column.

- Be prepared for emergency flooding of the column with nitrogen, if this is an option. Before the column is flooded with nitrogen, ensure that the fire inside the column is not too large, as nitrogen is ineffective in suppressing large column fires and titanium fires, because hot titanium will react with nitrogen. Ensure that all personnel are out of the column and the surrounding area, and ensure that no personnel return to the work location until the oxygen content in and around the column is verified to be safe.
- Ensure that adequate physical barriers are in place to prevent the ignition of column internals due to hot work.
- Work crews should be equipped with proper fire suppressants, and they should be prepared to evacuate the column in the event of an incident. Consider the need for firewater booster pumps for extremely tall columns.

Once the column has been verified to be safe and adequate barriers to packing ignition are in place, maintenance can be performed inside the column.

Performing Hot Work Inside the Column

The best practice for preventing fires involving metal structured packing or reactive metal packing is to remove all of the packing from the column prior to maintenance. This practice prevents hot work from igniting the packing and limits the amount of time during which the packing can spontaneously ignite. This option should always be considered during column shutdowns, despite the significant amount of time it takes to remove the packing from a large column. The risks associated with a large metal fire and the collapse of a column are catastrophic in terms of loss of capital and loss of life. If the packing is not removed from the vessel, physical and procedural barriers must be installed to prevent loss of life or property.

Physical Barriers to Packing Ignition

There are numerous methods that can be used to isolate structured packing from hot work. The first of these methods involves flooding the column with water up to just below the area where hot work is conducted. While this flooding drastically reduces the likelihood of a column fire, it creates a number of other problems including the potential for vessel rupture due to hydrostatic loading and the problem of disposal of the potentially contaminated water in the column. For small columns, flooding the column should present fewer issues. Before a large column is flooded, however, an analysis of the maximum hydrostatic loading that the column (and its support structure) can withstand must be conducted, and an evaluation of waste treatment must be made to determine if the large volume of water needed to fill the column can be disposed of properly. If the column cannot be flooded, the packing should be kept wet to the extent possible when the column is open to the atmosphere.

Another possible physical barrier involves the use of fire blankets to protect equipment below the welding area. The blankets should be robust in design and not susceptible to damage from falling objects. Blankets should be in good shape and must be rated for use in welding, per the manufacturer’s specification, because no current industry-wide standard exists for fire blankets used in welding service (Sullivan, 2002). When placing fire blankets inside a column, there should be no spaces between the blanket and the sides of the column through which hot slag or sparks could fall past the blanket into the packing.

One other physical barrier involves the use of a water shield to wet sparks and hot material as welding crews generate them. The shield involves a plastic sheet that covers a metal plate fitted to the column diameter. Water is added above the sheet to create a permanent pool of water underneath work crews.

A final physical barrier ensures that there is an air gap between welders and the packing below. An air gap alone is a very poor way to prevent column fires, as hot slag from welding may fall onto packing and start a fire. An air space could, however, increase the effectiveness of other physical barriers within the column.

Procedural Barriers to Packing Ignition

Procedural barriers to packing ignition should be implemented whenever maintenance activity takes place inside a column. These barriers are designed to prevent metal fires and help extinguish fires before they get out of control and include the following measures:

- Wetting sparks as they fly off of grinders or welding equipment.
- Ensuring that there is a fire-watch for every work group that is carrying out hot work and that each fire-watch understands the flammability risks associated with column packing.
- Ensuring that all workers performing hot work know how to initiate the emergency response plan and that they have access to buckets of water or class D fire suppression agents to extinguish small fires quickly.
- Keeping the work area clean for easy evacuation and access to the column for fire crews so that fires may be extinguished in their early stages.
- Continual monitoring of temperature and carbon monoxide at all levels of the column, including areas where hot work is being performed.

All crews performing hot work on the column should be informed of these procedures, and engineering or operations management should oversee all work on the column to make certain that proper procedures are not ignored.

Suppressing Metal Packing Fires

Metal fires burn at extremely high temperatures and the total surface area of a bed of metal packing can exceed a million square feet. This means that it may be impossible to extinguish a metal packing fire if the fire is not detected and extinguished early. Since agents that are specifically designed to combat metal fires are only practical for small fires, water is the only available medium to extinguish metal fires at most production facilities. Unfortunately, water is not always an effective suppressant for metal fires.

Metal fires burn hot enough to cause water to decompose into hydrogen and oxygen. This means that water that is dumped on a metal fire can immediately decompose to produce hydrogen, which may then explode. The result is that small amounts of water will actually exacerbate a metal fire. Large amounts of water can, however, extinguish a metal fire by cooling and smothering the metal (United States, 1994). Therefore, work crews should be given a large supply of water and packing fires should be extinguished early before the entire packed bed is consumed.

If water is not applied early to a packing fire or is applied in insufficient quantity, it is unlikely that it will extinguish a large packing fire. Based on industrial experience, most packing fires that are not extinguished early burn themselves out and lead to the significant (if not total) destruction of the packing inside the column and the column vessel.

Despite the fact that water is usually the only available suppressant for a metal packing fire, water has been known to react violently with titanium, and though it may be effective in suppressing small titanium fires if used in extremely large amounts (United States, 1994), it is not effective in suppressing large titanium fires, according to the National Fire Protection Association (NFPA, 1995).

Needed Research and Technology

The incident history of metal packing fires demonstrates that additional research is needed for combustion characteristics of steel materials, packing ignition sources, metal-oxide films to reduce combustibility, effective metal fire suppression methods, substitutes for metal packing materials, and safer packing and column designs, as discussed below.

- Combustion characteristics of steel materials under ambient conditions: Although there has been research regarding the combustion of steel in oxygen-enriched atmospheres, there is presently very little information concerning the combustibility of thin steel sheets under ambient conditions, which apply to steel packing in open distillation columns.
- Causes of packing fires: Definitive causes of many industrial packing fires are not known. Therefore, research is needed to investigate packing ignition sources, including ignition temperatures for metal packing made from various materials, thicknesses, and shapes.
- Metal-oxide films: Research should test the effectiveness of metal-oxide films and film damage on metal combustibility and identify column conditions that are responsible for damage to the films.
- Fire suppressant agents: Present class D agents are not suitable for large-scale application, and many of those that are effective (e.g., trimethylboroxane) are flammable and toxic. Effective and nontoxic liquid fire suppressants that are easily stored and delivered to the fire would make possible safer strategies for extinguishing packed column fires.
- Packing materials: Research to reduce or eliminate packing combustion could help to develop economic, corrosion resistant, and effective substitutes for metal materials, especially titanium and zirconium.
- Packing and column designs: Research is needed to identify features in packed columns and structured packing to reduce the risk of combustion. For example, the surface of structured packing or the interior of a packed column could be coated with materials that release fire suppressant compounds when heated.

Conclusions

Structured packing fires represent a potential hazard, particularly during maintenance. Metal packing can ignite because it consists of thin sections of material with a high surface to volume ratio. Factors such as the packing material and the presence of dusts or flammable materials can lead to packing ignition and combustion, which can cause destruction of the column internals or catastrophic failure of the column itself.

Best practices should be followed to prevent the occurrence of column fires and to reduce the possibility of a major incident in the event of packing ignition. Columns should be designed with safety in mind; and proper maintenance procedures should be conducted to make sure that workers are informed of potential hazards and that the column is opened to the atmosphere safely. The best practice to eliminate the possibility of packing ignition during hot work is the removal of packing prior to hot work in the column. If this is not possible, physical and procedural barriers should be put into place to prevent packing ignition.

Finally, fires inside packed columns must be extinguished quickly with extremely large amounts of water. Small amounts of water will only exacerbate the fire, and work crews will be unable to extinguish a column fire if it is not detected in its early stages.

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