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Fuels and Combustion Systems Safety: WHAT YOU DON'T KNOW CAN KILL YOU!

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Introduction

An industrial explosion from a gas piping project kills four workers in North Carolina. A boiler-related explosion in Michigan at a nursing home kills five. A power plant gas piping project in Connecticut kills five. These tragic stories may have made national headlines, but every year hundreds more are overlooked. These incidents prove that, regardless of their size or scope, when fuel systems and combustion equipment are at issue, the devastation can be massive. Many of these tragedies could have been prevented if guidelines and standards that are already in place were better understood and enforced.

Certainly, safety in industrial plants and manufacturing facilities where fuel-fired equipment is used has dramatically improved from 100 years ago, when boiler explosions and the related carnage were an almost everyday occurrence. However, incidents related to fuel systems and combustion equipment still occur far too frequently. It seems we have hit a plateau with fuel and combustion equipment safety. Maybe it's because of aging infrastructure, or a lack of enforcement of existing codes and standards. Or it might be related to the economy—economic downturns often take a toll on safety, training, and maintenance dollars.

Regardless of the reasons, it doesn't have to be this way. When lives are literally at stake, the excuses don't matter. Combustion equipment safety is critical to the daily operation of all facilities and the safety of every employee. With this paper, I hope to raise your awareness about this area of safety that few people know about simply because it is complicated and misunderstood. This paper will help you understand how to protect your employees from combustion-related incidents involving fuel systems and fuel-fired equipment (boilers, ovens, and furnaces) before you end up a headline. Hopefully this paper will encourage fuel systems and combustion equipment safety action at your facility before it is too late.

For the non-combustion person, this paper reviews basic gas train safety controls and concepts and provides an understanding of the most common problems we have found through our inspections and safety testing of more than 10,000 gas train systems, training thousands of skilled trades people, and developing corporate combustion equipment safety programs for some of the world's largest companies.

So let's take a look at the Top Ten issues related to fuels and combustion equipment safety that we have come across while inspecting plants and equipment.

1. Fuel Systems

One of the biggest issues related to natural gas explosions is that, in the industrial world, people just don't understand that natural gas piping repairs are different from other piping repairs. There is an appalling lack of training and understanding on this subject. If you are in charge of a maintenance crew or have any of this activity at your site—whether your own people do the work or not—you must get a copy of NFPA 54, *The National Fuel Gas Code* (NFPA 2009) and read it cover to cover. This document describes safe gas piping and repair practices.

There are six major steps to a gas piping repair. Each of these steps can be the subject of a separate paper and hours of discussion.

Pre-repair/Planning

1. Planning
2. Isolation
3. Pre-repair purge

Making the repair

4. Pressure testing
5. Post-repair purge
6. Re-introduction and light-off (the most dangerous part)

The importance of the pre-repair/planning phases cannot be overlooked. You don't just wake up one morning and decide to do a gas piping project. There are a lot of important planning and tasks that need to take place first for the job to be safe. This includes understanding at least the following:

1. Where are isolation points, and how will isolation be safely achieved?
2. Does the utility have involvement, and what are their requirements?
3. Is there an overall plan, and does everyone understand it?
4. Is there enough nitrogen? Does everyone understand nitrogen hazards?
5. Where will we purge to? (It must be outside of the building.)
6. Has re-introduction and start-up been discussed, including the unique hazards surrounding this activity?

The most dangerous part of gas piping projects is the re-introduction and start-up of the equipment. This seems to be related to a number of accidents. When you're purging there's a limited amount of hazardous material (it's just the pipe volume). When you're re-introducing there's an unlimited amount of gas that can make for horrible tragedies.

2. Equipment Issues

Most facilities do not have personnel properly trained in combustion equipment maintenance, start-up and shut-down procedures, or equipment operations. Most sites also do not follow proper fuel train interlock and safety testing guidelines, even though they are mandated by law.

Boiler safety laws passed by a number of states were intended to help more owners operate with safer equipment by mandating inspections and testing. Boiler inspections are mandated to be carried out in states and municipalities that have boiler safety laws. These are called jurisdictional inspections. In most states these laws call for inspection of water side systems (water level controls and pressure retaining devices), but not testing of fuel train safety devices.

In 26 states, ASME's *Controls and Safety Devices Code for Automatically Fired Boilers* (ASME 2004) has been adopted. It mandates actual operational combustion safety systems testing for units up to 12.5 million Btu/hour input (MMBTUH). Some states have also adopted NFPA 85, *Boiler and Combustion Systems Hazards Code* (NFPA 2004) for units that are over 12.5MMBTUH. This code also requires fuel train safety systems testing. In these states, jurisdictional inspectors may ask to see evidence of the required fuel train and safety interlock testing. Remember, it is beyond their work scope to do any of this testing. They might ask about it. If someone says, yes, it's being done, they most likely won't ask any details about how completely it was done (Exhibit 1).

Exhibit 1. This equipment with obvious fuel train problems gets a compliance certificate since jurisdictional inspectors have no fuel train inspection work scope.

3. "But It Was Just Inspected!"

People involved in boiler explosions or fires commonly say, *"But it was just inspected."* In their hearts, they believe that everything humanly possible was done to avoid a catastrophe because they just got a jurisdictional inspection and probably a state certificate to operate. People think that a jurisdictional boiler inspection is the magic bullet against problems. Very few people realize what a typical mandated jurisdictional boiler inspection is and is not.

Many large industrial clients are realizing that these mandated inspections are not enough to protect their most important assets—the lives of their employees. Some of these companies now have fuel and combustion equipment safety programs that go well beyond the minimal legally mandated requirements. These "self-audit" combustion system programs usually include an analysis for code compliance, but then go further into installation deficiencies, interlock testing, screening for maintenance practices that can impact safety, and assess technological advances that can improve safety.

4. Grandfathering Old Equipment

Jurisdictional inspectors often have their hands tied when it comes to what they can ask someone to do. What they are inspecting is often limited by exactly the letter of the law. For example, in many cases they can only evaluate equipment based on its code compliance for when it was installed. *Code compliance is not retroactive.* Codes usually change on three-year cycles, but compliance with new versions is optional. Safety codes have committees and evolve for a reason. It's because the technical world finds out how to do things better over time. The difference between what is installed and what the current code requires is called a gap. Conducting a gap analysis on equipment as it is installed can provide a road map for getting current and maximizing safety.

When a jurisdictional code inspector walks away saying everything passed, managers and others in a position of authority have a certain peace of mind. This could be 40-year-old equipment that requires many manual steps to operate safely and puts your site at serious risk of improper manual start-up or shutdown daily. These people need to learn that being technically "in compliance," but nowhere near the current code's level of safety, is not a moral victory (Exhibit 2).

Exhibit 2. During most jurisdictional inspections, archaic equipment like this 60-year-old boiler is passed based on the limited criteria for which it is screened. It could have dangerous fuel train controls and still be passed.

Consider also that, unless you are in a state that mandates ASME CSD-1 (2004) or NFPA 85 (200X) compliance, inspections rarely address gas trains and/or fuel system issues. Interlock and gas train testing is usually assumed to be a responsibility of the owner in these states. You can imagine that the level of compliance with these little-known testing requirements is much less in states where the issue of combustion control testing is not even on the table.

When it comes to process ovens, space-heating equipment, furnaces, and other industrial thermal processing equipment, there are very specific guidelines for levels of fuel train protection, safety and testing. These are spelled out in NFPA 86, *Standard for Ovens and Furnaces.* Unfortunately, very few people know about the NFPA 86 document. Often, industrial ovens and furnaces are custom pieces of equipment with safety controls that are assembled from components and not pre-engineered catalog systems. Unlike boiler systems, there are no mandated jurisdictional inspection programs for ovens and furnaces.

5. Interlock Testing

Burning fuel can be useful to mankind, as long as it is done as a controlled process. Control means that combustion takes place where we want it, when we want it, and at the rate we want it. Fuel trains are the complicated looking series of valves, piping, wires, and switches that provide this control (Exhibit 3).

Exhibit 3. This is a typical gas train with safety interlock components.

Fuel trains regulate the amount and the pressure of gas to burners. They also keep gas out of the combustion chamber whenever equipment is shut off. This is accomplished with a series of regulators, flow control valves and special shutoff valves. The special automatic shutoff valves are designed for low leakage and are spring loaded to close. These are called safety shutoff valves. Larger gas trains require dual safety shutoff valves in series. Some are also assembled into a piping arrangement that includes a vent between them for added safety. The vent and its piping are provided to allow any leakage past a shutoff valve to go outside the building when the equipment is off. The specific configuration of your equipment depends on your insurer and local code requirements.

Fuel trains also have components and sequences programmed in to ensure that safe light-offs happen. Some devices also make sure that fuel flow is immediately stopped if anything goes wrong during the operation of the equipment. Shut downs can occur from gas pressure switches, which attempt to make sure the gas pressures past the regulator are not too high or too low. Fuel trains also have air-flow proving switches to make sure that there is tje proper amount of air for purging fire boxes prior to light-off. These air flow purge switches then verify that air is also flowing while the burner is operating.

Exhibit 4. These are examples of typical flame detectors.

Flame-sensing components also must exist to make sure that flames are present whenever fuel valves are open (Exhibit 4). Other safety components include gas valve position switches for sensing that the fuel valve is at low fire prior to light-off. Your system could also include furnace pressure switches, high temperature limits, high steam pressure limits, and/or low water level cut-offs (Exhibit 5).

Exhibit 5. High/low gas pressure switches verify gas pressures are in the proper range.

All of these safety devices are logically linked or interlocked to a burner management system (BMS) safety controller. The BMS is the brain that supervises and sequences all of the light-off efforts, including the timing and adequacy of the purge prior to light-off and the time intervals allowed for getting pilots and main flames lit. The BMS then acts as your sentinel of safety and monitors all of the switches and safety conditions, while waiting to direct the fuel valves to close if a problem occurs (Exhibit 6).

Exhibit 6. The burner management system (BMS) is the "brain" that monitors/directs safe firing and operations.

All of the safety interlocks and switches are supposed to be checked on a regular basis by law, but with maintenance budgets among the first to be cut, proper checkouts and testing are seldom performed. Codes and manufacturers define what the testing frequencies should be for different types of components and safety systems. Frequencies of required inspection/testing range may be daily for some items like observing flames, or annually for safety shutoff valve tightness testing.

In our experience, when we come to a site where regular testing has not occurred, there is likely to be at least one switch or device that is failed on each piece of equipment. This is like having the brakes out on one wheel of a car.

When we do find sites that are engaged in some type of regular service or testing, they usually are not doing everything, or at least not doing everything well. It varies, depending on who is in charge, and that person's knowledge of the equipment or systems. And even if someone knowledgeable is doing the right thing, we often find that job rotations and turnover don't guarantee that this diligence will be in place for many years at a particular site. Because of this, we have not found much consistency among sites under anyone's corporate umbrella.

6. Passing the Buck: Even New Equipment Can Be a Problem

In many of the examples above, unsafe conditions developed over time from lack of upkeep or oversight. But how do things end up going wrong on newly installed equipment?

Consider a new facility being built that includes furnaces and a boiler heating system. The project could have been conceived and directed by someone that was part of your corporate staff. It may give you an underlying sense of confidence to think that degreed professionals designed the facility. The plans were then most likely reviewed by a number of people, including the city's building department, the local fire department, and an architect. A licensed contractor probably did the equipment installation. You may expect that, since a dozen skilled professionals have been involved, all has to be well.

But all may not be well. Here are some disturbing issues about this everyday scenario.

A. City Building Departments

City building departments often farm out the review of plans to architects or engineers, since they usually don't maintain enough staff to handle anything more than houses being built. The reviewers probably do a few projects a year, and have done some commercial projects with gas piping or combustion equipment, but they too are usually far from experts. They look for very significant and obvious local code-related issues; and may spend less than an hour on your drawings. This is most likely not a detailed examination of how your system was selected or installed, and it has *nothing* to do with how it is operated.

Building departments will then most likely send an inspector out to see your equipment after it is installed. The inspector is probably a retired tradesman. He will certainly know about residential work, since that is probably 90 percent of what he sees. It's very unlikely that this person would know much about industrial fuel piping, ovens, or boilers.

B. Corporate Project Engineering Staffs

Before starting CEC, I was a corporate staff engineer for a major oil company. We managed projects. We relied on specialized consultants for giving us advice on equipment selections. In most cases, the firms we used relied on vendors to tell them what they needed. This information was translated to drawings and a conceptual specification was generated. Rarely did this level of design include detailed gas train piping drawings and wiring schematics. In most cases, it was not possible to develop this until a specific equipment vendor was selected.

If the design process works correctly, the successful vendor provides detailed drawings for insurance approvals. This is then followed by a very detailed and thorough commissioning at the site to verify that all was installed and working properly. If these steps happen, then you are likely to be starting off with safe equipment. However, our experience shows that many times crucial information gets lost between the corporate specifications, the approved shop drawings, and what actually shows up on the job. Purchasing is always looking for the low bidder, which never helps this situation.

C. Project Architects

Architects receive little or no formal training in building mechanical or combustion systems. It is simply not usually in their scope. Most likely they will rely on the city's code officials, a hired consulting engineer, and/or a contractor or vendor to make this happen. The hired consulting engineer many times is no longer involved in the project after the project is bid, so there is no reason or incentive for the person who did the design to show up and see what was installed.

D. Project Managers

These are usually general contractors hired to handle scheduling and budgeting. Once again, it is not typically in their scope of work to spend much time or effort focused on meeting fuel, combustion, or boiler safety codes. They usually assume others will address those issues.

E. Insurance or Mandated Jurisdictional Inspectors

When it comes to boilers and the insurance world, you first need to understand who's covering what. A boiler is normally covered by two different insurance policies. One is the boiler/machinery (B/M) coverage for the pressure side, meaning the tubes, drums, water level controls and safety relief valves. The second part of a boiler's insurance is the property coverage, which covers the fire side, such as the fuel train, firebox, and refractory-related issues. There are

some companies who cover both the B/M and the property side and others that handle only one or the other. This is a matter you should investigate and understand.

Those that are on the property side may make recommendations to have safety controls and interlocks tested or have other fire side recommendations in their reports. These reports, and reports related to pressure side issues from B/M inspectors, can be seen by many other insurance companies, and can lead to some companies not bidding on insurance coverages and/or coverages becoming more costly for sites where more risk is perceived. In many cases, jurisdictional insurance B/M inspectors have their hands tied. They are only supposed to review pressure vessel and piping issues, including air tanks, water tanks, and boilers. They are not supposed to focus on issues like the gas piping at the site, the gas train component settings, control logic, and/or the burner flame pattern. It has been our experience that many property insurance-related inspectors spend more time looking at sprinkler and fire suppression issues than they do combustion equipment matters.

F. Local Fire Departments

Many local fire departments conduct fire prevention efforts, including compliance inspections of local businesses. These usually address fire doors, sprinkler systems, and general housekeeping issues. It would be rare for a fire department to have a boiler or gas equipment expert on its staff. Besides, boilers usually do not fall under any fire code.

So where does this all leave us? It makes for a case where it seems like a lot of people may be involved in the new combustion equipment installation, yet no one may have specifically been focused on combustion safety or fuel system issues. We inspect and test many newly installed systems only to find things wired wrong, safety devices that don't work, and/or equipment that doesn't comply with applicable codes. This makes people very upset, delays starting facilities, and costs companies a lot of money.

7. Human Error

Let's assume that, despite all that was just presented, you ended up with a properly installed and commissioned system. The staff, consultants, and vendors have now all left your site. Who is now qualified to operate and maintain the equipment?

Operations, maintenance, and people issues are now by far your biggest combustion equipment safety issue. The National Board of Pressure Vessel Inspectors (NBIC) statistics for boiler incidents show that nearly 40 percent of all deaths and accidents are caused by human error or poor maintenance. A lot of your success will now depend on the safety culture at your site.

The day after everyone has gone and you're now alone with your officially blessed equipment, one poorly trained person with a well-placed screwdriver can reduce your building to rubble and kill everyone around in less than five minutes.

8. Training

Too many facilities assume training is something that happens on the job in an informal sense. To them, it's information that gets passed on from person to person over coffee or in between baseball scores. There may have been more formal training years ago when the equipment was new. Now, maybe only half of those people are still around.

Codes offer very little specific direction regarding training other than to say that training is absolutely required and that it should be done regularly. The American Society of Mechanical Engineers (ASME) boiler code, in section VII, Subsection C2.110, states, “safe and reliable operation [of boiler] is dependent…upon the skill and attentiveness of the operator and the maintenance personnel. Operating skill implies knowledge of fundamentals, and a suitable background of training and experience. Regularly scheduled auto-manual changeover, manual operation, and mock emergency drills to prevent loss of these skills are recommended” (ASME 2004). This kind of training—particularly troubleshooting techniques and emergency mock drills—are ignored in most training programs we have encountered, even though they are clearly amongst the most important things that operators and maintenance staffs should understand.

The National Fire Protection Association’s NFPA 85, section 4.4.2, also identifies requirements for boiler operator and maintenance training (NFPA 2004). This information is helpful, but again rarely ever finds its way into boiler operator training programs. Even more peculiar is that where boiler operator licensing is required, licensing exams have very little to do with fuel train safety or maintenance. Instead, these exams and the training for them focus almost exclusively on water level and pressure vessel issues.

9. Preventive Maintenance

A comprehensive preventive maintenance program is your biggest defense against accidents and another vital part of staying safe.

If not properly maintained, combustion equipment can become less safe with every minute of operation. Dust, dirt, and debris accumulate in combustion air fans and burners. This changes air/fuel ratios. Some gas control valves get a little sloppier every time they are cycled. Pressure-switch diaphragms and contacts age. Water-level controls accumulate sludge.

These are all examples of possible operational or maintenance issues that could spell trouble for you and your site. The problem is that very few sites maintain the specific expertise required for proper combustion systems maintenance. The skills and knowledge required to do this work safely are considerable. These people must do this work regularly to stay sharp, not once or twice a year. They also need frequent training and specialized tools, such as flue gas analyzers. Most sites lack people with these skills and don’t have them properly equipped. In many cases, these people know enough to be dangerous. Don’t let your people try to do things like tune burners, change out firing rate control valves, or replace burner management systems unless they have been properly trained.

Sites that don’t want to have these problems with in-house staff sometimes blindly rely on outside contractors. Certainly, there are many fine contractors out there. However, you’ll want to be very careful before letting someone touch your combustion equipment. If you own and operate combustion equipment, you and your staff must have some core level of knowledge regarding safe practices before you can even hire the right contractor. You must ask a lot of questions about the specific level of training and experience that the person coming to the job has had. Make sure this person is not going to learn on your equipment. Remember, it’s not the reputation of the company that matters; it’s the specific expertise of the person they send.

10. Proper Documentation

Regardless of who does your equipment maintenance, another issue that you will have to be diligent about is maintaining your documentation. This means panel drawings, switch set points, purge times, and even component model numbers, and operational manuals. Many incidents have occurred from improper troubleshooting of problems because information was not readily available.

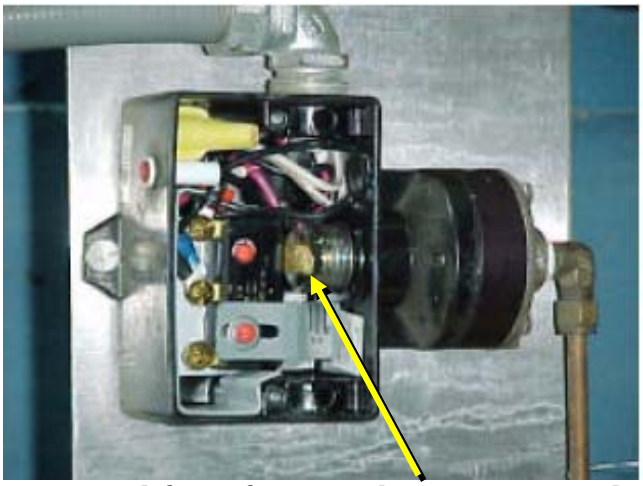

Exhibit 7. People get creative to defeat safety controls. Here is a Popsicle stick stuck into an air switch to force it to stay open.

Gas Piping and Combustion Incidents Can Be Avoided

Natural gas and combustion equipment safety continues to be considered a black art by many. Most sites have personnel that are not adequately trained in either the safe start-up/shutdown of equipment, daily operations, or proper testing and maintenance. Our firm's survey of industrial users found that less than ten percent actually perform manufacturer or code-required preventive maintenance, including testing of critically important safety interlocks. The combination of these two circumstances can spell disaster—and it has in numerous facilities.

When assessing your site's level of combustion equipment risk, remember the following:

1. **Most of the explosions and fire incidents, by far, have been due to human error.** All of the safeties and interlock equipment in the world won't help if someone has bypassed or jumpered-out safety controls (Exhibit 7). There is no possible substitute for proper training. Training has to include mock upset and hazard recognition drills. Your people need training, even if you will have contractors heavily involved at your site.
2. **Start-up and shutdown are your biggest risks.** You need clearly written procedures that everyone understands and agrees with so that consistent safe practices are in place with every shift and every employee.
3. **Make sure that you do regular and complete interlock and fuel train valve tightness testing.** Jurisdictional inspectors, even where they are mandated to be around, cannot be at your facility every day. Combustion equipment safety testing needs to be part of your organization's culture, regardless of what it costs and what the perceived hurdles are. You should comply with code requirements for testing even if some inspector is not forcing you.

4. **Create corporate guidelines for third-party combustion equipment reviews and commissioning for newly acquired equipment or for major upgrades.** Now that you see how little review and attention combustion equipment may receive from the time it's specified to when it's really operating, you may want a dedicated professional review of the design and what you are getting by a qualified experienced third party.
5. **Upgrade equipment for safety's sake.** There's no peace of mind in being grandfathered. Do not wait for a problem and let attorneys dictate upgrades that need to happen because of a lawsuit. Do a gap analysis proactively, and have a long-term plan to be compliant with the most recent codes.
6. **Prepare gas piping repair guidelines and enforce them**. This means line-breaking permits, and purging/isolation procedures. Provide the training to make the six steps of doing a gas piping project understandable. Provide the policies to make your new culture enforceable.

It takes a lot of effort to change culture and practices that have evolved over decades. In the beginning, you will probably get a lot of the same old, "Gee, we have been doing it this way for years," stories. Usually, the first year of a comprehensive combustion equipment testing and training program is painful. It takes a lot of effort and faith to fix things that "ain't broke" to some people. Certainly, the financial wizards will need to be convinced to upgrade equipment for the sake of safety, even though the upgrade may not increase throughput. (Although in many cases it will.)

Start with a gap analysis of your equipment's state of protection relative to current codes. Prioritize your needs and address them at a comfortable pace. Conduct a "human gap analysis" to identify the state of knowledge and skills regarding your operations and maintenance staff. Make training a regular and serious effort. The bottom line is that implementing comprehensive combustion equipment safety programs saves lives. The right thing to do is to be proactive. This is not the thing to do under the duress of catastrophes and death.

Once an incident occurs, it means years of court cases, job losses, higher insurance rates, and maybe even criminal litigation. It also takes years to overcome the stigma of safety credibility to your employees and the community. Taking the right steps ahead of time, and equipping your plant and employees with the training, knowledge and tools they need to do their jobs, saves lives. Because when dealing with combustion equipment, what you don't know *can* kill you!

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