FIRED HEATER SAFEGUARDING SURVEY

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Abstract

Refiners use a wide array of process heaters. The operation of these heaters poses a number of hazards that must be controlled, and are typically controlled using safety instrumented functions. The number and type of safety instrumented functions that are employed vary to a great degree from refiner to refiner and from site to site. This paper presents a summary of some of the results of a benchmarking study that was performed to determine the most prevalent practices in industry and establish the degree of adoption for some of the more common safety instrumented functions.

1.0 Introduction

Most refining organizations are very concerned with meeting the requirements of safety related standards and best practices in addition to their overall commitment to continuous improvement of safety and reliability. One common area for standardization among refining companies is the engineered safeguards that are implemented on fired heaters. There is a great benefit in standardizing the design of these systems because there are so prevalent. Like many refinery standard practices, standards developed to address fired heater safeguarding are often extensions of a related industry consensus standard – in this case American Petroleum Institute Recommended Practice 556 (API RP-556). API standards are extremely well adopted in the refining industry, and respected by both practitioners and regulators. Although the API RP-556 document is an excellent foundation, like most industry consensus standards it does not provide a completely definitive basis for design. API RP-556 contains many clauses where multiple options are available for meeting requirements and other clauses where the recommendations are not as strict as others (i.e., should instead of shall). Refiners typically address this limitation of consensus standards by issuing corporate standards that supplement other industry practices instead of developing a completely separate practice.

The author's organization performed a benchmarking study of the standard practices of refining organizations with respect to fired devices. The study was developed so that it would not only address common and well understood failure modes, but also address potential new approaches required as a result of new conditions and equipment, such as low NOx burners, and recent incidents and accidents related to fired heaters. Over the past several years, a number of accidents have occurred in the refining industry that were in whole or in part related to the following conditions.

- Improper use of bypass around heater fuel shut down valves
- Individual burner valves being left in the open position after occurrence of a shutdown resulting in inadvertent gas admission during subsequent light off
- Introduction of excess air into a fuel rich firebox subsequent to an operating anomaly

1.1 Benchmarking Survey Questions

The benchmarking was performed in accordance with a survey form that contained the information presented in *Table 1*.

Table 1 – Survey Questions

Which Automatic Trips are Implemented?
Fuel Gas High / Low Pressure Shutdown
Pilot Gas High / Low Pressure Shutdown
Loss of Flame on Main Burner - If yes, what method? (Flame rod, scanner, other)
Loss of Flame on Pilot Burner - If yes, what method? (Flame rod, scanner, other)
Low Process Flow (Pass Flow)
Low Excess Air / High Combustibles / Improper Fuel/Air Ratio - method for action?/detection?
Combustion Air Low Flow / Fan Not Running
Alarms
High Draft Pressure
High Bridgewall Temperature / Stack Temperature
High Process Outlet Temperature
Low Oxygen / High CO or High Combustibles
Permissives
Purge flow permissive – Automtic purge? – Material Used for Purging?
Fuel Gas Shutoff valve position permissive
Individual burner valves proved closed prior to light off (how?)
Pilot flame proven
Shutoff Valves
Double block and bleed on main / pilots
If a single valve, control valve or special purpose valve, what type?
Are bypasses used around shutoff/control valves for light-off or minimum firing
Pilots
Continuous pilots - Pilots sourced from a separate supply (i.e., natural gas)
Post Purge
Automatic Steam addition for purge upon initiation of a heater trip

The survey also developed information with regards to both new equipment projects and existing equipment installations, and the content of standards versus application of those standards in the field. Information regarding the content of corporate standards was requested in a yes or no question. Summary results for standards questions were then presented in terms of percentage of yes responses to the question. Information regarding the degree to which a practice has been implemented (both in new construction and existing equipment) was ranked from 1 to 3 where 1 corresponds to 'almost never' implemented, 2 corresponds to 'sometimes' implemented, and 3 corresponds to 'almost always' implemented. Summary results for implementation questions were then presented as the arithmetic mean (average) of all responses (one response per operating company).

While the form was oriented toward natural draft heaters, several of the questions were related to forced draft furnaces, specifically the questions related to combustion air flow shutdowns. The response from the survey indicated that there are some significant differences in how forced draft heaters are safeguarded as opposed to natural draft heaters. In some cases the author made revisions to survey forms returned by respondents, based on their comments, to ensure the focus of the study was natural draft heaters.

It is important to note that the commentary to the surveys is as important as the statistical data that was obtained. The rationale for why some companies chose certain practices over others gives a deeper understanding of how to obtain overall functional safety. Some statistical figures may be deceiving at first glance and should not used outside of the context of a full survey including all participant commentary. For instance, one respondent organization does not have fired heater standards at the corporate level, leaving all individual sites to set their own practices. As a result, a reported figure of less than 100% of companies require a certain safeguard as a standard practice, may actually mean that 100% of the companies that <u>have</u> standard require the safeguards – the remainder do not have standards, and thus would not require the safeguard as a standard practice. Furthermore, some hazards can be addressed in multiple ways. For instance, loss of combustion air flow can be detected using an air flow measurement, fan motor status, or fan shaft speed. If the survey reports that only fraction of respondents have a low combustion air flow shutdown that does not mean that the balance of respondents do not care about loss of combustion air, it means that other ways of detecting loss of combustion air are utilized at their sites.

1.2 Survey Participants

In order to understand the survey and put it in proper context, it is important to understand the demographics of the surveyed companies. Several operating companies responded to the survey (in some cases, multiple responses per company were received – in this case the responses were averaged for that company). All of these companies operate at least one refinery in the United States and are in the business as either pure-play refiners, or integrated oil and gas production, refining, and petrochemical companies. The survey team selected companies that have large market capitalizations, operate multiple refineries and have a large crude oil processing capacity. Significantly smaller companies with very low oil processing capabilities were not included in the study due to the potential that their practices may not reflect the best practices in industry.

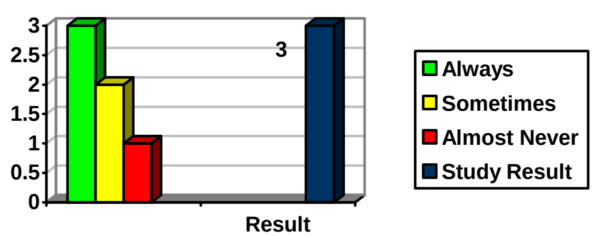
It should be noted that the results presented in this survey are based on a somewhat limited data set. Although the survey includes companies that represent the preponderance of crude oil processing in the United States, typically only one or two respondents per operating company completed survey forms where the organization might have more than a dozen refineries. Furthermore, many refining organizations have recently been built up through a series of mergers and acquisitions, leading to a wide variety of safeguarding practices within a single operating company. While most refiners are working diligently to standardize their operations, that task is not complete yet. While the author has made great efforts to provide a comprehensive analysis of operating company practices, data from every site in every organization could not be obtained. For operating companies where the author knew that practices varied to a great degree from site to site, we made an extra effort to survey multiple sites to get an average response.

3.0 Survey Results Summary

A summary of some of the results of the survey is shown below. The information presented below is simply a statistical compilation of the responses to the survey forms and notes containing general commentary on the results and the comments that the respondents provided in their survey forms. While the original survey analyzed a number of design scenarios, the summary results presented here only represent the application of these design features on new equipment.

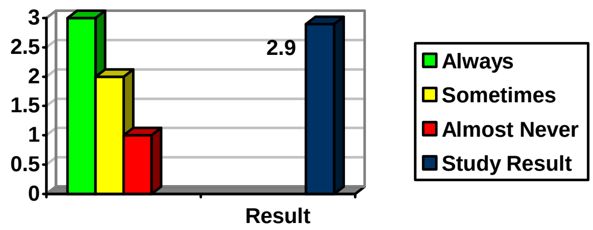
3.1 Shutdowns

Fuel Gas Low Pressure Shutdown



The low fuel gas pressure is the most common shutdown employed on fired heaters. All companies 'almost always' implement this shutdown on their new and existing equipment. Of the surveyed companies that have corporate standards, only one does not require that low pressure trip be implemented, but even that standard requires that the shutdown must be 'considered' based on a risk assessment and further requires that the low pressure trip shall be implemented unless continuously operated separately fuel sourced pilots are utilized on the heater.

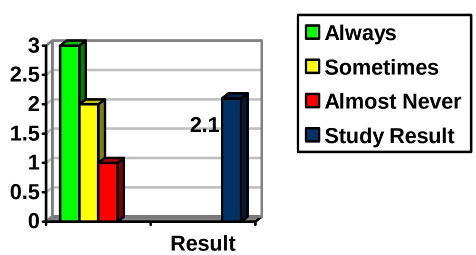
Fuel Gas High Pressure Shutdown



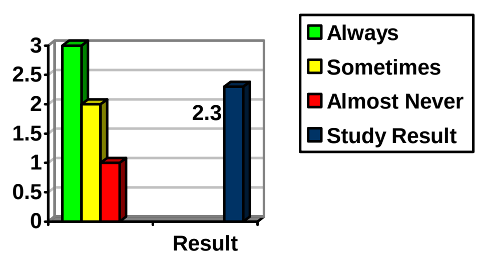
Of the operating companies that have fired heater safeguarding standards, all require implementation of a high pressure trip in their most current form. The high level of adoption of the high pressure trip is based on the knowledge that hazards resulting from high pressure fuel gas situations can not (in all cases) be safeguarded by other means such as flame scanners and continuously operating pilots. Even though standard practice dictates that this shutdown be implemented, existing equipment and even in some cases new equipment may not employ this shutdown. One respondent noted that even though their standard requires the high pressure shutdown, some projects may choose not to implement the trip. If this decision is made it is based on knowledge (and testing) of the burners to determine their stable operating range and verification that the fuel supplied to the burner can not reasonably exceed that pressure based on the design of the fuel supply system.

Pilot Gas High / Low Pressure Shutdown

High Pressure



Low Pressure

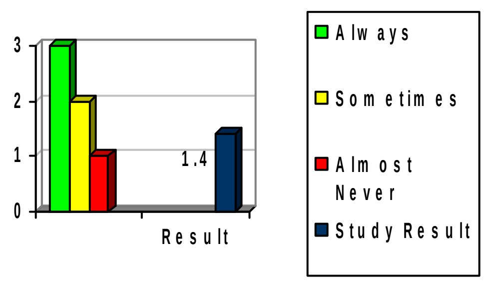


The figures reported for adoption of high pilot gas pressure shutdowns are difficult to interpret without considering the context in which they were generated and the respondent notes regarding how pilots are utilized at the various operating company sites. While the figures show that the preponderance of operating companies do not require shutdown due to high pilot gas pressure, that should not be taken to imply that high pilot gas pressure has been deemed to be an insignificant risk. Not all companies employ continuously operating pilots, and as such their standards would not require a high pressure pilot gas shutdown, not because the risk is insignificant, but because the pilots are not typically in operation. Of the operating companies that elect not to employ a high pilot gas pressure shutdown, their rationale is that the risk is tolerably low. A high pressure event in the pilot during normal operation would typically be mitigated by action of the main flame, leaving only startup and pilot-only operational modes as situations where the plant is at risk. In addition, many deem the likelihood of generating a pressure high enough to extinguish the pilot flame as very unlikely.

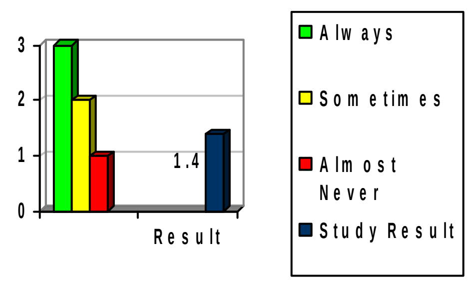
Many of the same considerations in analyzing the response to the question of high pilot gas pressure shutdowns apply to low pilot gas pressure shutdowns. Low pilot gas pressure shutdowns are more common for users of continuous pilots than high pressure shutdowns due to the increased likelihood that a low pressure pilot gas condition can occur and generate a hazard.

Loss of Flame on Main/Pilot Burner Shutdown

Main



Pilot

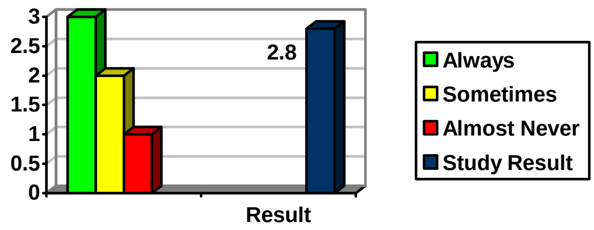


Shutdown on loss of flame at the main burner (as detected by flame scanners, flame rods, pattern recognition cameras, or other device) is not a very common shutdown, and many refiners feel that the hazards that would be prevented utilizing this function are adequately safeguarded using other means. It was noted by several participants that a loss of flame on the main burners' shutdown is not required to be measured or cause a shutdown if continuously operated pilots that are sourced with a supply of fuel that is independent of the main burners.

It should be noted that the figures presented above represent natural draft process heaters. Use of flame scanners is much more prevalent on induced and forced draft process heaters, and almost always done on boilers (true purpose-built boilers, as opposed to process heaters where steam generation is incident to the process purpose of the heater).

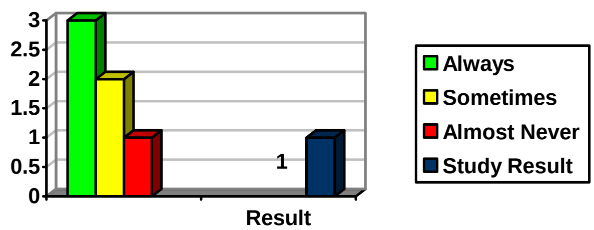
Shutdowns based on flame detection on pilots are also not extremely common. Although not common, one operating company employs pilot burner loss of flame shutdowns as a standard practice and almost always implements this shutdown in practice. The rationale of this operating company is that if the pilot burner is in operation, then a lot of the hazards that might occur as a result of main burner fuel system anomalies will be effectively mitigated by the pilot. As a result, they place a high degree of importance on ensuring that the pilot flame is always available to perform its safety purpose.

Low Process Flow (Pass Flow) Shutdown



Heater shutdown based on low flow of process material through heater passes is very common. For those respondents whose standard practice does not require this trip, analysis is required to ensure that loss of flow through the heater tubes does not pose a significant hazard and are still recommended in coking services. Even for those whose standards require the shutdown, in some cases exceptions are allowed if an analysis of the type of heater and the process fluid is performed to determine the detrimental effects of loss of flow is performed that shows the risk posed by loss of flow is tolerable.

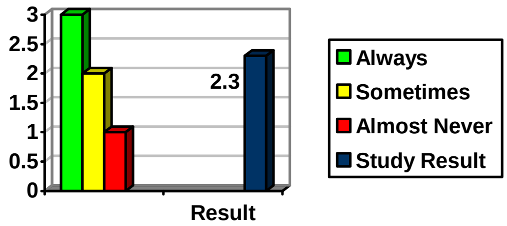
Low Excess Air / High Combustibles / Improper Fuel/Air Ratio Shutdown

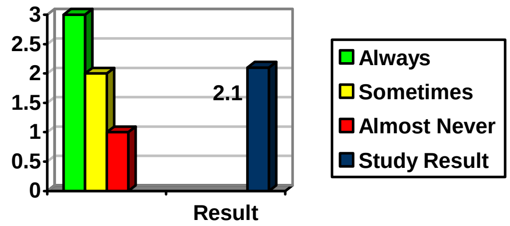


None of the operating company respondents employ any automatic actions to mitigate the hazards posed misoperation of a fired heater resulting in an oxygen deficient fuel rich atmosphere in the heater firebox. The basis of safety for preventing realization of fuel rich firebox hazards is through good control of furnace draft, in some cases employing closed loop control based on oxygen analyzer measurement, and thorough operating training to ensure that if an oxygen deficient firebox condition were to occur that the proper control action of cutting fuel gas, as opposed to adding air, is used.

Combustion Air Low Flow / Fan Not Running Shutdown

Low Air Flow Fan Not Running

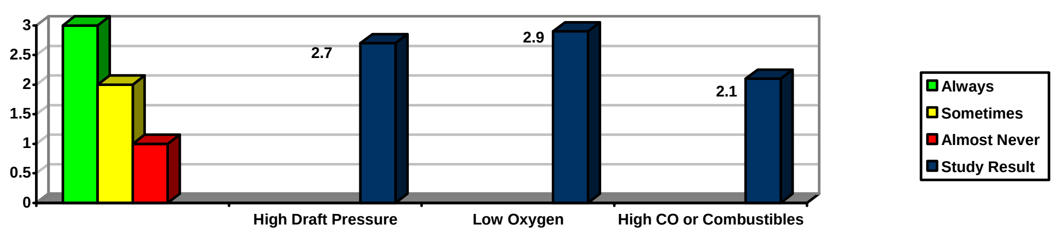


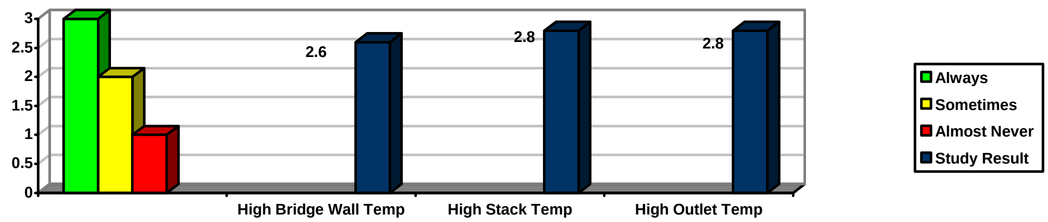


It was noted that in almost all cases, if a heater is equipped with a forced or induced draft air supply system, some sort of shutdown was employed to detect a loss of air condition. While the reported numbers for standard practice and implementation of either low combustion air flow trip or air fan not running trip were near 50%, these figures are not indicative of their importance to process safety, but to the preference of what type of measurement is used for causing the shutdown. The two primary means of measurement were direct measurement of combustion air flow or an auxiliary contact on the combustion air fan motor starter. For new installations there is a strong preference to move toward direct measurement of combustion air flow due to the more comprehensive and direct indication of a hazardous condition. In some cases, both fan not running and low air flow were used as measurements that can result in a heater shutdown. In the case of one of the respondent operating companies, their preference for detecting insufficient combustion air was the measurement of the speed to the fan motors.

3.2 Alarms

Alarms are very consistently applied across all operating company respondents, and very frequently applied. The only alarm where application was more represented by ‘sometimes’ than ‘almost always’ is the High CO or High Combustibles alarm. It was noted that application of this alarm is becoming more prevalent as regulatory requirements increase.

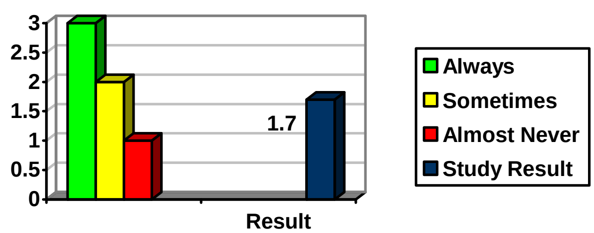




3.3 Permissives

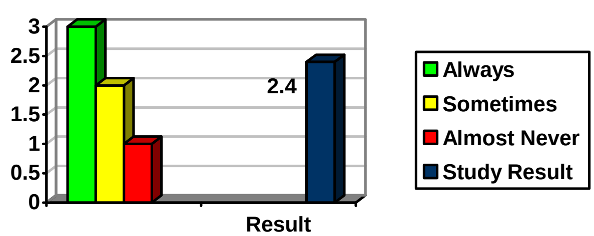
When reviewing the permissives section it is important to note that the intention of the survey was to primarily review the operation of natural draft heaters, as opposed to forced or induced draft heaters. It was noted that the degree to which permissive functions are implemented is much greater for heaters with forced or induced draft fans and also for boilers.

Purge Flow Permissive



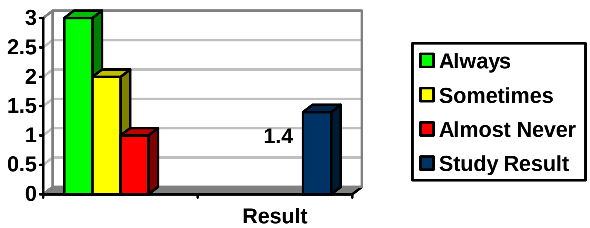
Operating company respondents that employ purge flow permissives were in the minority, but application was significant enough to warrant consideration. It is important to draw a distinction between this function and a subsequent question regarding automatic firebox purge. If automatic firebox purge is employed, then a purge flow timing permissive is virtually always used, but automatic purging is not required for a purge flow timer permissive. Some operating companies employ this permissive by measuring the heater draft or purge steam flow and ensuring that the measured variable is of a sufficient quality for the preset time interval.

Fuel Gas Shutoff Valve Position Permissive



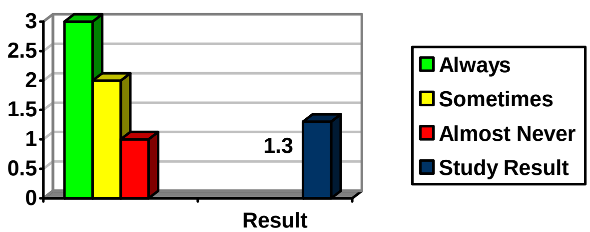
The fuel gas shutoff valve permissive is quite common in practice while not as often directly required in corporate standards. Where this shutoff is not employed in an automatic fashion it is always performed through operator procedure. When the permissive is employed in an automatic fashion it is typically performed using limit switches. No use of valve positioner signals for this purpose was noted.

Individual Burner Valves Closed (Seal Test) Permissive



Closure of individual burner valves is always ensured prior to light off of the heater, but it is rarely performed automatically, unless the heater is of a certain type that has a very large number of burners, such as a steam reformer or an ethylene cracker. Only one respondent has historically been doing this type of permissive on a regular basis and only two respondents employ this type of permissive in the standards for new equipment (on all heaters). Of these companies, neither requires a 'seal test' type permissive on all heaters – and typically does not use the seal test methodology unless there is an extremely large number of burners (e.g., more than 100).

Automatic Firebox Purge

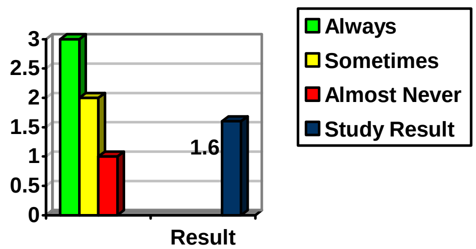


The results presented above show that implementation of automatic purges on natural draft heaters is very rare; in fact, only one site of one respondent organization is known to regularly utilize this technique.. Only one respondent incorporates this as standard practice, and most of their existing heaters do not employ the permissive. Where forced draft heaters are used, the automation of purging is more frequent, but still would only be characterized as "sometimes" for existing equipment. More new installations of forced draft heaters implement automatic purging of the firebox utilizing the forced/induced draft fans, but not enough to categorize the implementation as “almost always”.

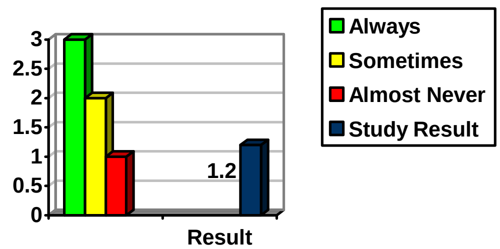
The medium used for purging is extremely consistent with the type of heater being used. For natural draft heaters, steam was virtually always used. For forced/induced draft heaters, combustion air was almost always used. No significant usage of any other purging medium (i.e., nitrogen) was identified.

Flame Proven Permissive

Pilot



Main

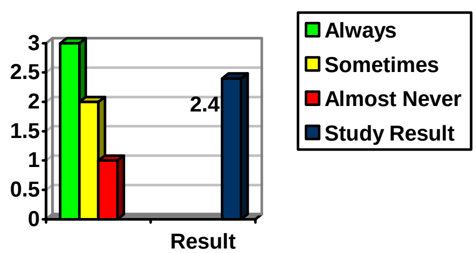


The survey indicated that flame proven permissives are not common. Flame proven permissives are typically performed automatically when there is a loss of pilot flame trip, but not performed if there is no associated trip.

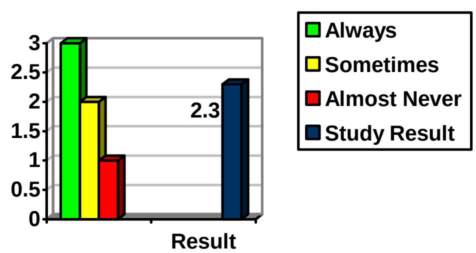
3.4 Shutoff Valves

Double Block and Bleed Shutoff Valves

Main



Pilot



Use of double-block-and-bleed arrangements on heater fuel gas supplies is not uncommon now and is becoming even more common. Most of the respondents are requiring double block and bleed as standard practice, and many require in their standard that double block and bleed be considered during the SIL analysis process. In actual practice, use of double-block-and-bleeds is also prevalent.

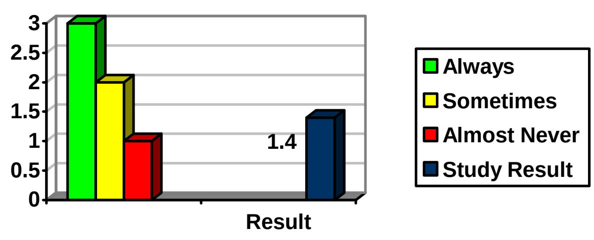
Use of a double-block-and-bleed arrangement provides two benefits over a single valve. First, a positive isolation is ensured, preventing hazards resulting from fuel gas leaking across a single valve in to the firebox when the valve is closed. Second, the use of two devices to perform the shutdown (in a 1oo2 vote) decreases the probability of failure on demand and increased the safety integrity level (SIL) that can be achieved by the functions. These two goals can and are being achieved by measures other than use of double-block-and-bleeds by a number of respondent companies.

For positive isolation, some refiners isolate the fuel when not in use as a standard practice by blinding and rolling a spool piece in the gas supply. The main fuel source is typically not reconnected to the main burners until after the pilot burners have been lit, virtually eliminating the risk of leaking main shutdown valves and open individual burner valves for the case of a cold start. One refiner noted a move to quick disconnects to facilitate the practice of isolation.

To decrease the probability of failure on demand of gas shutoff some refiners are electing to use increased diagnostics and more frequent testing in lieu of increasing the number of valves. Where required to meet elevated SIL targets, partial stroke testing is sometimes utilized. Partial stroke testing is performed commonly either using manual jamming devices or with purpose built automatic testing devices – no strong preference between the testing types emerged in the survey.

In some cases, the use of double block and bleed arrangements of pilot gas systems was noted to be a matter of consistency between shutoff practices between the main burners and the pilot burners, and not for risk reduction in and of itself.

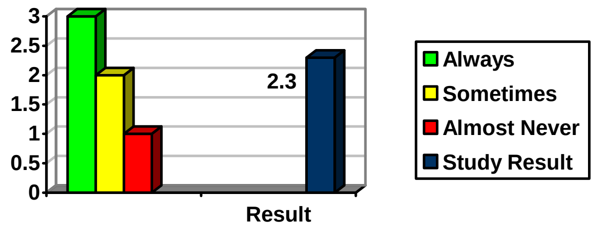
Bypasses Valves around Shutoff Valves (for Light-Off or Minimum Firing)



Bypasses around shutoff valves are not very frequently used and are falling out of favor in situations where they were traditional used. One respondent noted that the only instance where bypasses are allowed are for ‘seal testing’ and in this case the bypass was a manual ‘dead man’ valve and the bypass itself was only 1/4” tubing. The preferred design is moving toward either ensuring that SIL targets can be met with equipment that only needs to be tested at a turnaround interval (i.e., double block and bleed) or use of partial stroke testing.

3.5 Pilots

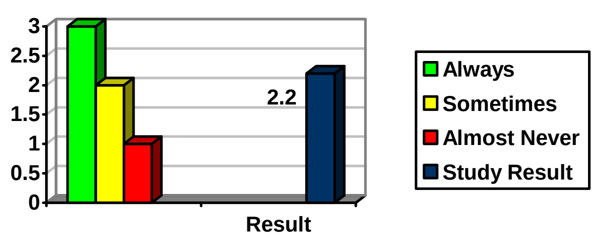
<u>Continuously Operated Pilots</u>



While the use of continuously operated pilots is not required by the preponderance of operating companies, actual use of continuously operating pilots is very common. Many of the standards that do not strictly require that this practice be implemented do require that it be considered. These standards require that if continuous pilots are not used that other means of enhancing safeguarding be employed, such as loss of flame detection.

Some operating companies tend to have very strong opinions about the use of pilots that permeate through their organizations. One operating company relies on continuous pilots as a primary means of safeguarding, including heater shutdown if loss of pilot flame is detected. Two operating companies that responded to the survey do not employ continuous pilots as a standard practice. One of these companies uses pilot burners to light the main burners, but then takes them out of service. Another company does not install pilot burners at all; instead, they light the main burners directly. This company stated that they find pilot burners to be very unreliable and hard to maintain due to the increased propensity toward clogging due to the smaller orifice size and lower flow rates. Their preferred means of ensuring safe operation is through strict control of burner pressure and well established testing and knowledge of the safe operating limits of the burner system.

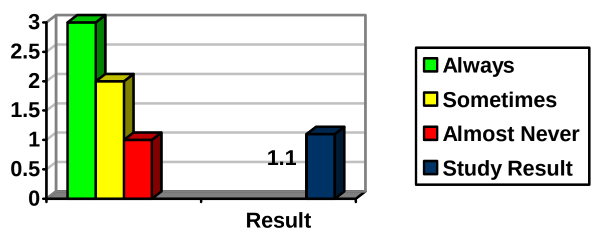
<u>Pilots are Source from a Separate Supply (i.e., Natural Gas)</u>



Use of a separate source of pilot gas is somewhat common where practicable, but not to the degree where it can be considered to be ‘almost always’ employed. It should be noted that the figures shown here are somewhat skewed because those respondents who do not use pilots at all are also indicated as not using a separate supply. This means that use of a separate supply of pilot gas for those respondents who use pilots is actually somewhat higher than what is shown.

3.6 Post Purge

Automatic Steam Addition upon Natural Draft Heater Shutdown



The surveys indicate that this action is virtually never done automatically. Only one respondent noted that this is done automatically in some situations, and another respondent noted that this practice is employed regularly at one of their sites, but never at the others. In fact, some respondents noted that this practice is intentionally avoided due to the potential that spurious operation of the function or use of the function in non-optimal conditions may actually cause damage to the heater.

4.0 Conclusions

Benchmarking is an effective tool in assisting refiners to determine how to implement portions of standard practices where the requirements are ambiguous, open to interpretation, or multiple options are available. In many cases the practices that are implemented are remarkably consistent and form the basis for “recognized and generally accepted good engineering practice”.