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Safety Controls and Burner Management Systems (BMS) On Direct-Fired Multiple Burner Heaters

Paul Chau, P. Eng. Vice-President (Born Heaters Canada Ltd.)

www.adico.co
info@adico.co

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1. Introduction

Safety controls on direct-fired heaters have continuously evolved over the recent past, and the evolution has accelerated over the last five years. This has been due to the introduction of government legislation which actively enforces the application of existing codes. Heater designs and quality standards have followed the practice of API 560. For most operating companies this is now mandatory and used as a minimum standard with individual companies adding their own requirements. With Safety Controls or Burner Management Systems, this evolution has not occurred.

Although some detailed and prescriptive guidelines have been around for many years, the rate and degree of adoption varies significantly within the industry. Most operating companies have their own "standard", which may still vary from facility to facility. In addition to this, for each installation, it is not unusual for adjacent heaters built two years apart to have a different BMS design, simply because different engineering contractors built them. With increasing government legislation and regulations as well as mounting lawsuits for accidents in which applicable codes and guidelines have not been adhered to, it is important to review the BMS requirements for both existing and new heater installations.

New legislation has been introduced to standardise the requirements. In most provinces of Canada the code is CSA B149.3, which is an adaptation of NFPA, however this is currently legislated as a minimum requirement.

Most operating companies within North America are implementing BMS in new and existing heaters in accordance with required guidelines; however there are some installations that still rely only on manual operator intervention or the plant Emergency Shutdown (ESD) as the safety control. The most common reason provided by these companies is that they have operated with the manual system and absence of flame monitoring equipment for years without incident; why should an investment be made in a BMS now?

The general consensus is becoming to standardise the requirements of a safe and operable BMS for each heater, to ensure a safe light off and normal operation while reducing the amount of nuisance trips. But we all must bear in mind that the safety of personnel and environment is of the utmost importance; as such a proactive approach must be taken.

2. Background

In the past, most heaters have operated on temperature control from the outlet temperature to a control valve in the main gas line, with a single shut-off valve upstream on the Control valve. This shut-off valve was either automatic with the plant ESD or operated manually with an Operator action, with each company having various additions to this basic concept.

The following is a list of new requirements that are common to various heater and BMS codes.

1) Mandatory Purging.
2) Permissive Interlocks
3) Double Block and Bleed systems
4) Pilots and Ignition Systems
5) Dedicated Flame Monitoring Systems
6) High / Low Pressure, Temperatures and Flow.
7) Combustion Air and Draft Pressure Alarms and Controls
8) Dedicated Logic Solver

Each of these requirements have been developed due to incidents that have occurred because of the lack of them.

3. Mandatory Purging

The most important function of the heater control system is to prevent the possibility of an accumulation of combustible gas followed by accidental or improper ignition sequence resulting in an explosion. Correct pre-ignition purging of the heater is crucial to the safe operation of the heater.

The normal practice for the purging of a natural draft heater has been to allow a period of time for a heater to naturally purge. Typically this would have been 20-30 minutes on a cold light off, and would have been at the discretion of the operator. The alternative is to purge with steam, if available. Caution must be taken when doing so to prevent possible steam condensation from affecting the operation of the ignition and flame monitoring instrumentation.

The timed purge is to be proven. The codes imply that there has to be a means to prove there has been four volumes changes or air in the heater prior to light-off. It is not possible to measure the air flowrate during a natural purge. Therefore the options available to provide a proven purge are:

a) Purge Blower or Fan
b) Steam purge from radiant section

c) Induced Draft Purge (via Steam educator in the Stack)

Furthermore, depending on the jurisdiction there may also be a minimum purge flow rate that must be adhered to.

A time to achieve the four volume changes may be calculated from the required flow rate. In the event the purge does not continue for the prescribed time or required purge, permissives are no longer met and a re-purge is required. Only when a successful purge is completed can any ignition source be introduced.

CSA B194.3-05 Section 9.2 Pre-purge

> 9.2.1: When either an intermittent or interrupted pilot or a direct transformer spark ignitor is used to light the main burner and the combustion air supply is by mechanical means, the appliance control system shall provide a proven purge period prior to the ignition cycle. This purge period shall provide at least four air changes of the combustion zone and flue passages at an airflow not less than 60% of that required at maximum input.

NFPA 86 Section 5-4.1 Pre-ignition (Pre-purge, Purging Cycle)

> 5-4.1.2: A timed pre-ignition purge shall be provided. At least 4 Standard Cubic Feet (SCF) of fresh air or inert gas per cubic foot (4 m3/m3) of heating chamber volume shall be introduced during the purge cycle.

4. Permissives & Interlocks

These can be numerous and may include all of the items on the BMS. The interlocks are usually designated on the P&ID with the symbol **"I"**. These are used in the configuration of the operating procedure and logic so as to ensure the safe sequential operation of the heater particularly in start-up and during operation. The permissives are an integral part of the start-up and light-off procedure. The main importance of the interlocks is to detect the need for partial or total shut down of the heater.

Typical interlocks would include high/low fuel and pilot gas pressure, high/low stack temperature, loss of flame, high/low firebox pressure and loss of combustion air. In addition to these general trips each heater must be examined individually to determine if additional trips may be required due to the heater design or configuration. These non-standard trips are designed to protect the heater and personnel from tube and structural damage that may occur from improper operation for a long duration.

5. Shut-off Valves

The safety shut-off valves are the key component in the BMS to prevent the accumulation of an explosive mixture in the heater. Standard practice is to provide automated safety shut- off valves installed in a double block and bleed configuration on the main and pilot headers. An additional safety shut-off valve should be located on each individual burner for multiple burner systems. These shut-off valves must also be certified for use safety shut-off valves. In accordance with CSA requirements these valves need to be certified to CSA 6.5 certified and per NFPA requirements these valves need to be FM-7400 listed.

During normal operation the bleed is automatically closed on light-off request and likewise opens automatically on shut down. The vent valve is to be proven closed prior to opening of the shut-off valve; on shutdown the upstream shut-off valve is to be confirmed closed before the vent valve opens to prevent fuel from being unnecessarily vented. The valves must also be in their de-energized state and proven prior to heater purge and start-up.

The configuration discussed above works well for a single burner system but this cannot be applied to multiple burner systems; unless they are all to operate in tandem. In order to keep the heater running in the event of a single burner failure the fuel gas must be isolated from the failed burner. Strict adherence to the codes and guidelines would require two separate safety shut-off valves piped in series for each burner. An exception is provided in NFPA that would allow for the shutdown of a single burner, provided that all burners fire into a common combustion chamber and certain conditions are met.

The CSA code even goes one step further and requires a double block and bleed arrangement on each main and pilot burner. Although the code does not provide the same exception afforded by NFPA a variance application can be made to the authority having jurisdiction to implement a similar valve train. The addition of more valves does not necessarily equate to a safer heater from a reliability standpoint.

CSA B194.3-05 Section 5.3 Safety Shut-off Valves

5.3.1: Safety shut-off valves shall not be bypassed

5.3.4: An appliance that has a maximum rated input in excess of 10,000,000 Btu/h (3000 kW), up to and including 50,000,000 Btu/h (15 000 kW), with single burner or multiple burner flame safeguard controls shall be equipped with not less than two automatic safety shut-off valves piped in series and wired in parallel that are certified in accordance with ANSI Z21.21/CSA 6.5 and marked C/I.

5.3.5: An appliance that has a maximum rated input in excess of 10,000,000 Btu/h (3000 kW), up to an including 100,000,000 Btu/h (30 000 kW), with multiple burners that have multiple burner flame safeguard controls shall be equipped with not less than two automatic safety shut-off valves per burner, certified in accordance with ANSI Z21.21/CSA 6.5 and marked C/I, one of which shall be in the common valve train and may be of the fast opening type. The downstream valve shall be provided with a mandatory manual-reset function to open.

5.3.9; an appliance that has a maximum rated input in excess of 10,000,000 Btu/h (3000 kW), up to and including 50,000,000 (15 000 kW), and a burner manifold pressure in excess of 0.5 psig (3.5 kPa) shall:

a) have main burner shut-off valves supervised by an approved valve proving system that prevents main burner automatic safety shut-off valves from opening when a leak is detected; or

b) Be equipped with and automatic vent valve that is:

(i) Normally open and energized to close; (ii) sized in accordance with Table 2;

(iii) installed in a vent line that is connected into the burner valve train immediately downstream of the first automatic safety shut-off valve in the main burner valve train; and

(iv) wired in parallel with the first automatic shut-off valve. There shall be no other valve or valves installed in the vent line NFPA 86 Section 5-7 Safety Shut-off Valves (Fuel Gas or Oil)

5-7.1.1: Safety shut-off valves shall be utilized as a key safety control to protect against explosions and fires.

5-7.1.2: Each safety shut-off valve required in 5-7.2.1 and 5-7.3.1 shall automatically shut off the fuel to the burner system after interruption of the holding medium (such as electric current or fluid pressure) by any one of the interlocking safety devices, combustion safeguards, or operating controls.

NFPA 86 Section 5-7.2 Fuel Gas Safety Shut-off Valves

5-7.2.1: Each main and pilot fuel gas burner system shall be separately equipped with two safety shutoff valves piped in series.

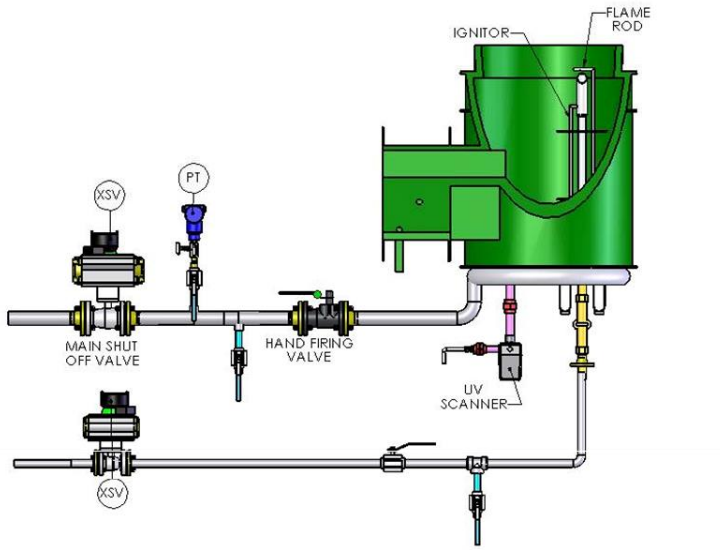
5-7.2.2: Where the main or fuel pilot gas burner system capacity exceeds 400,000 Btu/hr (117 kW), at least one of the safety valves required by 5-7.2.1 shall be proved closed and interlocked with the pre-ignition purge interval.

Certified Shutoff Valve

6. Pilots and Ignition Systems

Unfortunately the majority of heaters still in use within the industry rely on a manual ignition system. This means the heater is manually lit by the operator inserting an oily rag or an ignition torch to the base of the burner. With today's technology and easy accessibility to the electronic ignition system it is no longer necessary to manually light the heaters and potentially place the operator in harm's way.

The electric ignition system consists of an ignition rod provided with the burner and a high voltage ignition transformer. When all interlocks are cleared and permissives are in place the ignitor lights the pilot burner which then in turn lights the main burner. An electronic ignition system, controlled by the BMS, eliminates the need for the operator to provide an ignition source for the burners; which is considered to be the most dangerous part of the start- up procedure. As the BMS controls the ignition of the burners the heater purge cannot be so easily bypassed.



Typically each burner is provided with its own pilot and ignition system. We recommend that a continuous pilot be used. The dedicated pilot is to ensure that there is always a continuous source of ignition for the main burner. Hence the pilots are continuously in operation and need to be from a secure fuel source such as natural gas. Continuous pilots provide a safe stand- by mode of operation in case the main burners are to be turned off and negate the need to re-purge the heater after a main burner shutdown. The heat release from the pilots is minimal and will not cause any damage even if there is no process flow through the coils.

CSA B194.3-05 Section 8.2 electric Ignition Systems

8.2.1: Electric ignition systems of other than the direct transformer type shall not be used to ignite pilot or main burner gas except with the approval of the authority having jurisdiction.

8.2.2: Direct-transformer spark ignition shall not be used to ignite pilot gas unless the pilot is proved.

NFPA 86 Section 5-4.1 Pre-ignition

(Pre-purge, Purging Cycle)

5-4.1.5: Prior to re-ignition of a burner after a burner shutdown or flame failure, a pre-ignition purge shall be accomplished.

Exception; Repeating the pre-ignition purge shall not be required where the conditions of (a), (b) or (c) are satisfied.

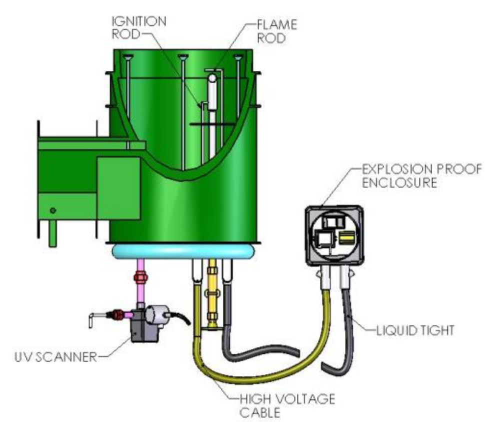
a) The heating chamber temperature exceeds 1400˚F (760˚C)

b) For any fuel-fired system, all of the following conditions are satisfied: (1) each burner and pilot is supervised by a combustion safeguard in accordance with Section 5-9; (2) each burner system is equipped with safety shutoff valves in accordance with Section 5-7; and (3) at least one burner remains operating in the combustion chamber of the burner to be reignited.

c) All of the following conditions are satisfied (does not apply to fuel oil systems): (1) each burner and pilot is supervised by a combustion safeguard in accordance with Section 5-9; (2) each burner system is Equipped with a gas safety shutoff valve in accordance with Section 5-7 and (3) it can be demonstrated that the combustible concentration in the heating chamber cannot exceed 25 percent of the LEL.

7. Dedicated Flame Monitoring Systems

Each burner is equipped with its own flame monitoring devices, independent detectors are required to supervise the pilot and the main flame. Exceptions may be made depending on the type of pilot and burner. In most installations two different detection techniques are used, a flame (ionization) rod to monitor the pilot flame and an UV (Ultraviolet) or IR (Infrared) Scanner to 'see' the main flame. Flame rods are typically used on the pilot flame as they are more cost effective, however the same detectors should not be used on the main flames as these typically run at a higher temperature and the flame rod would burn out in a short amount of time.



Some certified flame monitoring devices have an adjustable flame failure response time, typically from one to four seconds. The Canadian code further requires that any flame monitor that can fail in the "flame-proving" mode be supplied with a self-checking mechanism, which means the burner will remain on for longer than 24 hours. As the flame monitor is the most critical instrument in detecting a loss of flame and initiates the isolation of the fuel gas it is recommended that a self-check scanner be provided for all systems regardless of the firing cycle. Dependent on the size of the burner, it may only take several seconds to accumulate an explosive mixture, which explains the need for such a device.

CSA B194.3-05 Section 9.4.4

9.4.4; Flame detectors that can fail in a flame-proving mode shall be of the self-checking type when the burner firing cycle can last longer than 24hr without cycling.

CSA B194.3-05 Section 9.1.1 Combustion Safety Control System

9.1.1; A combustion safety control system shall

(i) De-energize the main burner fuel shutoff valve in the event of a flame failure

(ii) Within 4 s for an appliance that has an input in excess of 400,000 Btu/h (120 kW)

NFPA 86 Section 5-9 Combustion Safeguards (Flame Supervision)

5-9.1: Each burner flame shall be supervised by a combustion safeguard having a maximum flame failure response time of 4 seconds or less, that performs a safe-start check, and is interlocked into the combustion safety circuitry.

5-9.2: Each pilot and main burner flame shall be supervised independently.

8. Alarms and Shutdowns

Alarms and shutdowns provided by the heater's instrumentation provide added safety and permissives to allow the system to transition from different stages of heater operation in a proper and safe manner. There is some instrumentation typical to all systems and others that are dependent on the size, purpose, and configuration of the heater. The instrumentation is located on the fuel gas trains and the heater itself. In the past, switches have been widely used for these applications for various reasons, however it is strongly recommended that transmitters be used in lieu of switches. Switches may fail in an unsafe position without providing any indication until the unit is required to operate. Transmitters report back dynamic information and have built-in diagnostics, so they are able to provide indication of failures. Considering the losses involved if an incident was to occur, it is far more cost efficient to use the more reliable transmitters.

The alarms required for the fuel gas are common for all systems. These are high / low main fuel gas pressure, and high / low pilot gas pressure. These are required to keep the operating pressure of the burners within the design parameters provided by the burner manufactures. Operation outside of these limits will cause flame instability among other problems. If a forced draft fan or blower is required to provide combustion air to the blowers, a low combustion air flow alarm and low flow trip is to be provided.

Other measurements and alarms should be provided in order to protect the heater itself from improper operation. A high stack temperature will warn of possible leakage in the convection section, resulting in an uncontrolled fire, whereas a low alarm will protect from possible acid gas condensation. A high-high stack temperature will cause a shutdown of the main burners.

Heater draft measurement and alarm will help ensure that the heater operates within the design draft profile. Operations outside this range may cause flame instability and improper/incomplete combustion.

Dependent on the process fluid, heated low process flow alarms may be required. If the process fluid is susceptible to either coking or degradation at temperatures above design, it is recommended that a low flow alarm be provided and a main burner shutdown on loss of flow. Low process flow will also result in high tube skin temperatures as not enough heat is being removed from the tubes.

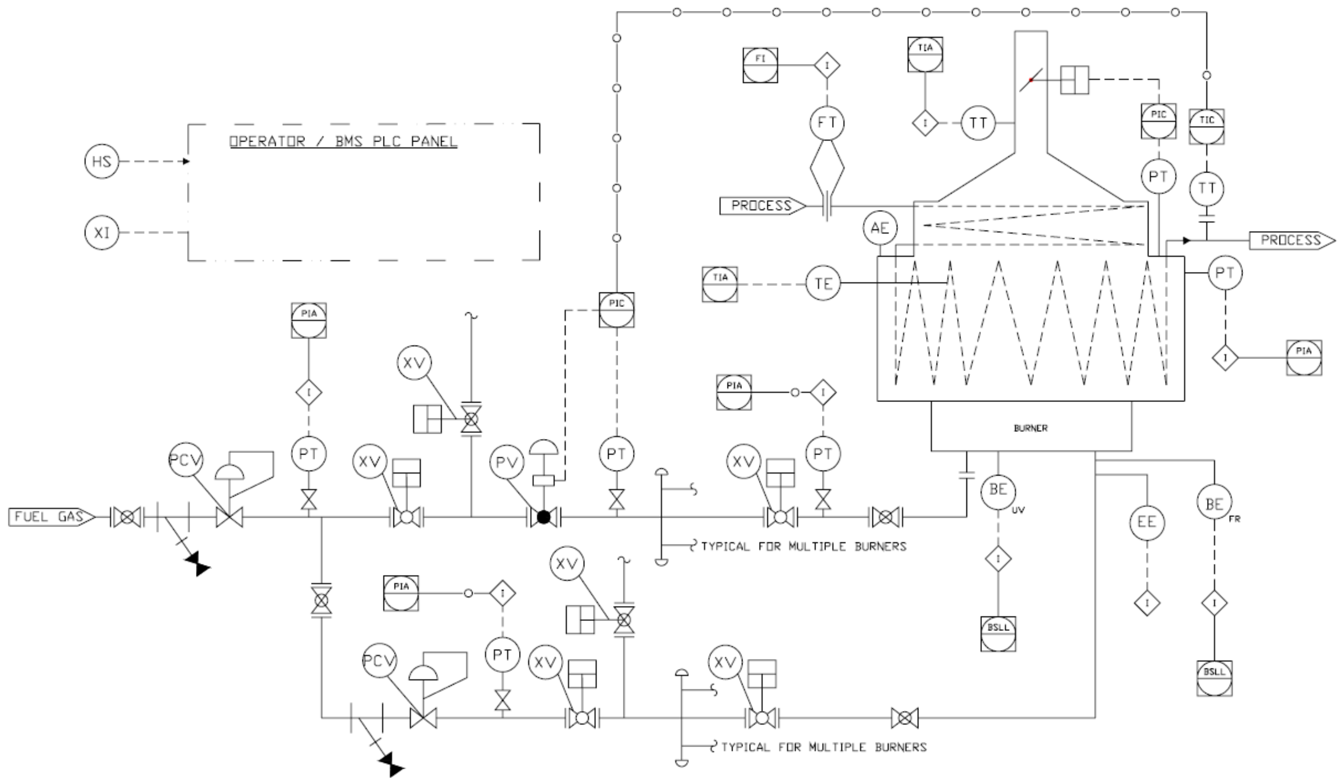
CSA B194.3-05 Section 9.5 Gas Pressure Safety Limit Control

> 9.5.1: When the design outlet pressure of an appliance pressure regulator is in excess of 0.5 psig (3.5 kPa), a high- pressure safety limit control device shall be installed and shall initiate shut-off of the supply gas if the pressure at the point of connection exceeds the highest normal operating pressure by more than 25%. ….
>
> 9.5.2: For appliances with inputs in excess of 400 000 Btu/h (120 kW), or with the design outlet pressure of the appliance regulator being in excess of 0.5 psig (3.5 kPa), a low-pressure safety limit control device shall be installed and shall initiate shut-off of the supply gas if the pressure at the point of connection drops below 50% of the lowest normal operating pressure….

NFPA 86 Section 5-8 Fuel Pressure Switches (Gas or Oil)

> 5-8.1: A low pressure switch shall be provide and shall be interlocked into the combustion safety circuitry.
>
> 5-8.2: A high gas pressure switch shall be provide and shall be interlocked into the combustion safety circuitry. The switch shall be located downstream of the final pressure-reducing regulator
>
> 5-8.3: Pressure switch settings shall be made in accordance with the operating limits of the burner system.

GENERAL BMS OVERVIEW



9. Combustion Draft / Pressure Alarms and Controls

Heater draft is the motive force that will ensure proper air and flue gas flow through the heater. The most critical draft point is at the arch as it is the controlling variable in the design of the burner and heater itself. This measurement is a critical indicator in the operation of a fired heater and alerts the operator to any tendency to go positive.

Although this is normally not a shut-down device, it is closely linked to opening the stack damper blade. The pressure control loop consists of a pressure transmitter located at the heater arch and an actuator on the stack damper. A low draft pressure (high firebox pressure) alarm should be added to this transmitter. The control loop is to be configured such that the stack damper opens when there is a low heater draft. In the event that the heater draft is still too low but the stack damper is 100% open the burner firing rate must be reduced.

10. Dedicated Logic Solver

Traditionally most BMS's have been implemented using a discrete series of relays and switches as the logic solver. When designed correctly these hardwired panels may prove to be very reliable. Unfortunately the permissives and interlocks on such systems are easily bypassed. With the advent of the microprocessor, unitized flame safeguard controllers have been introduced. These units provide the required logic too safely start and stop the heater. The drawback of these units is that they are only designed to control single burner systems.

The area of biggest change in BMS systems as of late is the ability to use a Programmable Logic Controller (PLC) as the primary safeguard and logic solver. Certain conditions must be adhered to in order to validate their use, which vary between different codes. Common requirements are that a power or hardware failure will not prevent the system from reverting to a safe condition and an external watch dog timer must be used to monitor a dedicated output channel. Any failures will cause the system to revert to a safe condition. As technology advances and the introduction of true safety rated systems progresses, these requirements and guidelines will inevitably change.

CSA B194.3-05 Section 9.7 Programmable Controllers

> 9.7.1: When a microprocessor is used as a primary safeguard device, the requirements of Clause 9.7.2 shall apply.

Note: Programmable logic controllers (PLCs) and distributed control systems (DCSs) form part of a family of microprocessor-based burner management systems (BMSs) and diverse sequence control applications. These devices execute their application programs in a rigidly organized sequential manner. They are extensively used because of their high reliability and their fault-diagnostic capabilities. In recent years, the functionality and use of the two processors, PLCs and DCSs, have merged, and for the purpose of these requirements, they are designated micro-processor based systems.

> 9.7.2: Programmable controllers may be used for the monitoring, sequencing, and control of all aspects of burner or process, or both …
>
> 9.7.2.2: the microprocessor-based system shall be solely dedicated to the BMS. Logic for functions other than the BMS application shall not be part of the I/O structure, memory, or software program.
>
> The following shall apply:
>
> a. The software program shall reside in some form of non-volatile memory storage ….

b. A watchdog timer internal to the BMS processor shall monitor the program scan time…

c. In the event of a power failure, the microprocessor-based hardware and software shall not prevent the system prom reverting to a fire-safe condition…

d. The BMS shall be equipped with a master fuel trip relay ….

e. Redundant processors with automatic transfer schemes shall be permitted …

f. The designer of the BMS and the software shall provide the end user and the authority having jurisdiction with the documentation…

NFPA 86 Section 5-3 Programmable Controllers for Safety Service

5-3.1.2: In the event of a power failure, the programmable controller (hardware and software) shall not prevent the system from reverting to a safe default condition. A safe condition shall be maintained upon the restoration of power.

5-3.1.3: The control system shall have a separate manual emergency switch, independent of the programmable controller that initiates a safe shutdown.

5-3.1.4: Any changes to hardware or software shall be documented, approved, and maintained in a file on the site.

5-3.2.1; A programmable controller-based system specifically listed for combustion safety service shall be permitted where applied in accordance with the listing requirements and the manufacturer's instructions.

5-3.2.2: A programmable controller not listed for combustion safety service shall be permitted to monitor safety interlocks, or to provide burner control functions, provided …

PLC Panel with Push Buttons

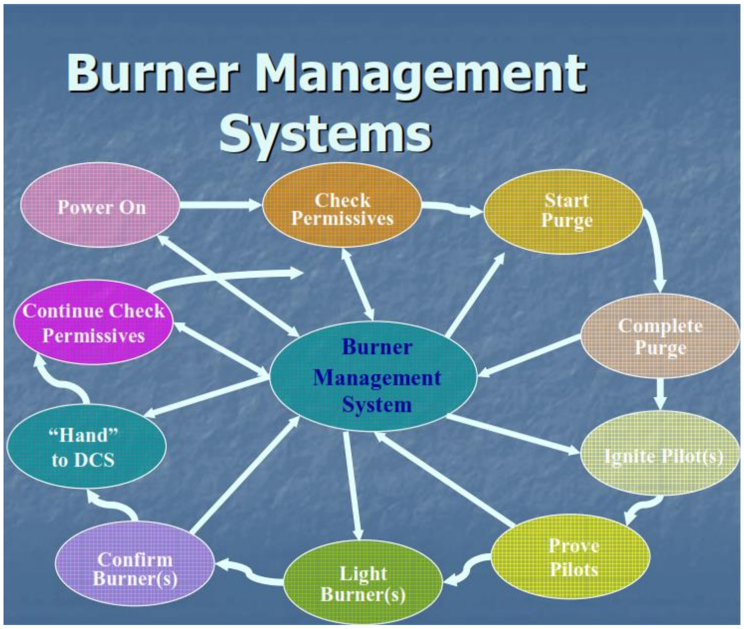
11. Operating philosophy

The main function of the BMS is to allow and ensure the safe start-up, operation, and shutdown of the Fired Heater. Once the logic is configured and the system properly commissioned the BMS will provide a safe and consistent operating sequence. The human interface will guide the operator so that the heater may be safely operated, and if needed, be quickly and safely restarted.

The following sequence of operation is typical for most Fired Heaters.

1) Initially, the PLC will check that all the permissives and interlock are in place to allow start up.
2) Start Purge. The PLC will check that the permissives are at their correct status. The system will typically wait for the operator to request the heater to start, although all permissives are met and the heater is ready to purge. Once the heater start/purge is requested a pre-set timer will commence. Assuming the timing is not interrupted by an Interlock activation, it will continue until complete. Once finished, it will notify the operator that “Purge Complete” has been accomplished.
3) Ignite Pilots. Once the purge is completed, the operator will be notified that the system is ready to start the pilots. The pilot header double block and bleed valves will energize. Instantaneously, the individual local pilot firing valves will open and the ignition transformers will be energized. The pilot valves and the ignition transformers will only be energized for a maximum of 10 seconds. If the pilot flame is not detected within this time the individual pilot isolation valve will close.
4) Prove Pilots. Each pilot has its’ own dedicated flame detector, which in most cases is via a flame rod. Once proven, the individual pilot valve will hold in and continue to burn, in the event a pilot is not lit.
5) Light Main Burners. Before the main burners are lit, the PLC will continue to check the permissive to ensure it is safe to light the main burners. The two main permissives are that there is sufficient flow in the process coils and the pilot burners are proven. The system then proceeds to energize the main header vent and shut-off valves. The first burner will light at the minimum fire rate. A five second trial for ignition is provided from the time the individual isolation valve is opened until the detection of the flame. If the flame is not detected, the individual main burner isolation valve is de- energized.

6) Confirm Main Burner Status. Once this is achieved the system is ready to be ramped up to operating conditions. This is usually performed manually until the process variable is close to the operating set point, then the temperature and gas flow/pressure controllers can then be switched to auto mode.



12. Conclusion

There are a number of codes and guidelines pertaining to the safety control and burner management system for direct fired heaters. The controlling code within Canada is CSA B149.3, but the most common guideline referred to around the world is NFPA 86. Due to changing government legislation as well as safety and insurance concerns, there is an increase in the necessity to upgrade or install the heater safety systems (BMS) to comply with published codes and guidelines.

These codes and guidelines are specific when in regards to the valve train and certain safety instrumentation. There is little aid when incorporating the safety and operability aspects of the overall heater and BMS unit. Unlike boilers, there are a variety of configurations and process fluids that a direct fired heater may be designed for. As such, there are many safety interlock and operation permissives that must be reviewed on a case-by-case basis.

Adherence to the published codes and guidelines is a great start and will create a good foundation for the heater's safety system. In order to design the system for maximum reliability and operability, each system should be reviewed individually and the safety controls designed accordingly.

Fuel Gas Skid (BMS)