



# Designs of Boiler Burner Management System

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## ABSTRACT

Boilers are used in many industrial facilities to generate electricity or produce heat, steam and hot water. Many hazards are occurring on the boiler affecting boiler operation. Within unsafe conditions, boiler hazards might cause explosions, property implosions, injuries and death. This project outlines changes on piping and instrumentation diagram (P&ID controller) of boiler pipelines improving smooth operation and boiler efficiency following control requirements of international standards and safety regulations such as National Fire Protection Association (NFPA) and American Society of Mechanical Engineers (ASME) to be checked on Boiler Burner Management System and all safety requirements to be developed. Moreover, the project presents the safe arrangement of boiler components in P&ID designs for each part of the boiler to achieve functional safety requirements and comply with the original approach for Burner Management Systems.

**Keywords:** Boiler; Control Valve; Piping and Instrumented Diagram (P&ID); Burner Management System (BMS); National Fire Protection Association 85 series (NFPA85); Master Fuel Trip (MFT)

## I. INTRODUCTION

### A. Boiler

Boiler is a generating unit that generates steam which is pumped to generator connected with turbine to generate electric power [1]. The steam might be used for personal uses such as producing heat and hot water. Boilers contain two basic systems. Steam water system where water is heated and converted to steam (see Fig.1) [1].

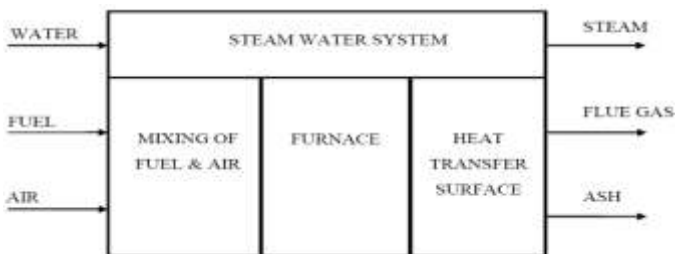


Figure 1. Steam Boiler Diagram

The fuel air-flow gas system provides the heat which is transferred to the water. The system inputs are the fuel and air required to burn the fuel. The fuel and air chamber is also referred to as the wind-box. The system outputs are the flow gas and ash [2].

### A. Burner Management System (BMS)

The general term used for a boiler safety is burner management system (BMS). BMS is considered a combustion safeguard, boiler safety system, burner control system, flame safeguard system, safety shutdown system, furnace safeguard supervisory system, emergency shutdown system or a safety instrumented system (SIS) [3].

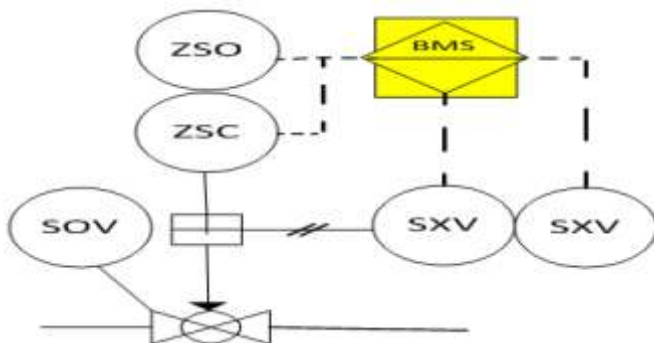


Figure 2. Burner Management System

The main requirement for BMS is to monitor boiler operation [1]. BMS protects equipment from implosions and people from injury or loss of life by initiating a safe operating condition and fuel trip. The code authority that covers practices in this area is the National Fire Protection Association (NFPA). The published documents are the 85 series [2,6].

### C. National Fire Protection Association (NFPA)

The NFPA 85 is a Boiler operation and Combustion Systems Hazards Code 2011 Edition [6]. The Code ensures safe boiler operation and prevents explosions and property implosions [2,6]. The Code establishes minimum requirements for boiler design, installation, operation, training and maintenance of boilers, fuel burning, air supply, and combustion products removal [6]. The most common cause of boiler explosions is human error.

## II. RELATED WORKS

### A. P&ID Designing

Randall Newton discussed Piping and Instrumentation Diagram (P&ID) designing in a research was made on "DuPont to standardize on Bentley Open Plant P&ID". P&ID is a developed form of Process Flow Diagram (PFD). P&ID is a schematic drawing representing showing:

- Final elements and control and mechanical equipment with names and numbers
- All valves tees and reducers with identifications
- Process piping
- Vents and drains
- Flow directions
- Control inputs and outputs
- Interlocks
- Annunciation inputs
- Computer control system inputs
- Instruments and control loops
- Electrical data such as tracing and motor drives

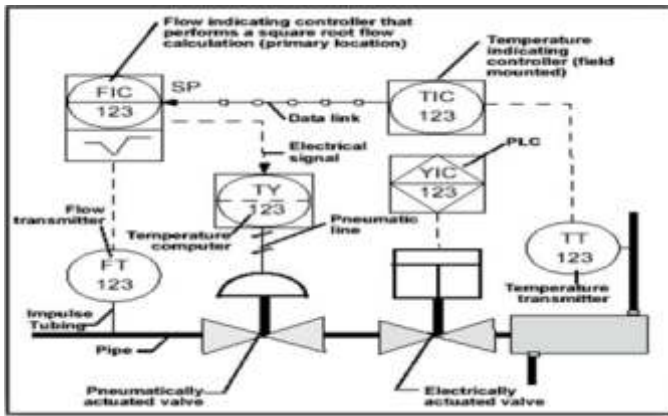


Figure 3. P&ID with Identifications

Small plants have a single P&ID. Larger plants have separate diagrams representing process lines and equipment such as steam, condensate, feed water, atomizing media and fuel etc.

**B. Boiler Control**

Peterschmidt and Taylor proposed “Boilers and Boiler Control Systems” which is based on control methods that affect boiler operation and efficiency calculations [4]. As there are several methods that affect boiler start-up, shutdown and flow parameters such as pressure, temperature and flow volume [1].

“Steam explosions in boiler ash hoppers” is another study outlines steam hazards in steam boilers and the proper control methods that help to avoid steam explosions [5]. The main cause of steam explosions is ash leakage [3].

In another study, the fire protection systems are essential for industrial facilities using insulation materials designed with passive fire protection systems which can avoid fires, injures and save life and property [7].

Dukelow explained boiler mechanism, boiler control methods such as start up, purging and shut down and boiler automatic control (BAC) in his book “The Control of Boilers” [1]. The book outlines the proper methods for boiler installation, testing and maintenance. Boiler hazards cannot be avoided but minimized to operate the boiler in a safe way [1,6].

**III. BOILER HAZARDS**

Boilers, furnaces and burners are considered as high-risk machinery within oil and gas industry. Today’s boilers are operated at high conditions of pressure and temperature [2]. Also the flammable and toxic inputs creates hazardous conditions should be controlled in a safe way to avoid any explosions, property implosions, injuries and loss of life [6]. Listed below some boiler hazards [6,7,8,9]:

- Boiler Transmitter Quality Trip (Boiler Airflow).
- Boiler Drum Level Low-Low (Transmitter).
- Boiler Steam Drum Pressure High-High.
- Control Air Pressure Low-Low.
- Low Flame Strength.
- Wet Steam during Atomizing.
- Excessive Water Temperature.
- Fire & Gas Master Boiler Trip.
- FD Fan Not Running.
- Loss of All Flame.
- Delay in First Gas/Oil Burner Start.
- Gas Header Test Fault (No Burner in Service).
- Air Heater Not Running Trip.

These hazards are considered as the main high-risk boiler hazards that might cause boiler explosions. The first action shall be taken to control those hazards and avoid explosions is shutting off fuel valves and creating master fuel trip (MFT), but fuel tripping is not the only action that should be taken to avoid the disaster [6]. Unfortunately there are some historical incidents of boiler explosions confirm the probability of disaster occurrence in the future. Table 1 summarizes most recent boiler explosions [11].

TABLE I. MOST RECENT BOILER EXPLOSIONS

| Date              | Event                     | Location                                  | Killed | Injured |
|-------------------|---------------------------|---|--------|---------|
| May 25, 2003      | SS Norway                 | Miami, Florida, USA                       | 8      | 17      |
| July 29, 2001     | Madina County Fair Ground | Madina County, USA                        | 5      | 40      |
| June 29, 1995     | USS Willamette            | USA                                       | 0      | 7       |
| November 27, 1977 | Bitterfeld Railway        | Bitterfeld, East Germany                  | 9      | 45      |
| January 24, 1962  | British Railways          | Bletchley, Buckinghamshre, United Kingdom | 0      | 2       |

To combat the boiler explosion hazard, a proper arrangement of boiler components was developed by creating perfect P&ID designs of boiler burner management system to reduce the hazard to a minimum [2]. These designs also describe the boiler operation, light off and shut down additional burners as necessary and trip the fuel whenever the continued operation appears to be unsafe [6]. The code authority that covers practices in this area is the National Fire Protection Association. The published documents are the 85 series. Any action to design or modify the design of boiler safety protection circuits should include adherence to these guides [3].

Those standards state boiler control methods in general ways which were used as references to fulfill boiler control information and safety requirements that lead to a fully understanding of boiler mechanism, control methods and minimum requirements for P&ID designing[1,3]. The main standards are:

- NFPA – National Fire Protection Association
- ANSI – American National Standards Institute
- ASME – American Society of Mechanical Engineers
- ISA – International Society Of Automation

The P&ID designs of the boiler were developed with design and simulation software such as “MICROSOFT VISIO” and “ANSYS” in accordance to NFPA 85 codes with the proper arrangement of boiler components required by the functional standards in order to optimize the equipment design.

**IV. P&ID DESIGNING**

Boiler could be operated with high efficiency and high safety control methods to produce a continuous supply of steam with the lowest cost of boiler inputs. Steam generators and boilers are large plants have separate P&ID designs representing process lines and equipment such as steam, condensate, feed water, atomizing media and fuel etc. Each P&ID design was made following minimum requirements of designing parameters such as control (pressure, temperature and flow), safety, cost and efficiency.

TABLE II. SYSTEM IMPROVEMENT

| Design Parameter | Improved System                 | Improvement  |
|------------------|---------------------------------|--|
| Control          | Oil & Gas Skid                  | Pressure - Flow - Control Valve Sizing                 |
| Safety           | Burners                         | Flame Detectors  |
| Cost             | Oil & Atomizing Media Skid      | Removing Extra Final Elements                          |
| Efficiency       | Heat Losses Efficiency Equation | Higher Heating Value (HHV) - Lower Heating Value (LHV) |

**A. Control:**

**A.1 Pressure Control**

**Disadvantage of current design:**

Fluid flowing inside a pipeline should be controlled with a specified pressure limit provided by manufacturer of the system with pressure regulator device as shown in figure-4. A pressure transmitter (PT) measures fluid pressure flowing inside the pipeline and transfer the measure value to pressure controller (PLC). Pressure controller compares the measured value with the set point value provided by manu-

facturer and sends a correcting electrical signal to the control device to respond to the difference and control fluid pressure. If the fluid pressure goes high exceeding the set point and manufacturer limit, the pressure regulator shall detect the overpressure and opens the relief valve to release the high pressure or it might close the control valve and trip fluid flow. A failure or fault in the pressure transmitter (PT) in a pipeline with single pressure regulator, the system will fail to take a safety action to relief the high pressure and trip the boiler which is an explosion hazard.

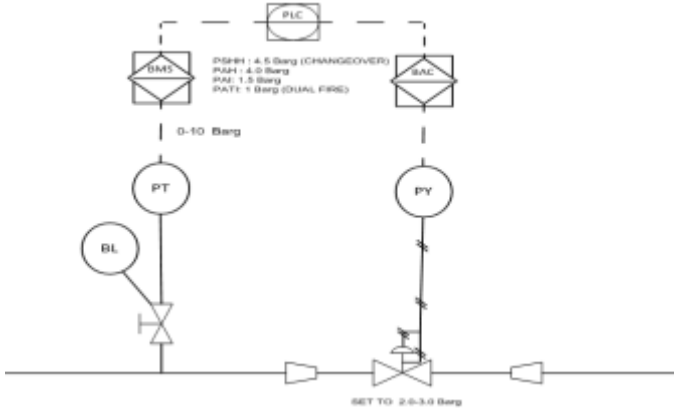


Figure 4. Single line pressure regulator for gas skid

**Design Improvement:**

Several devices shall be used to prevent overpressure in the pipe line system of the boiler from exceeding the safe limit causing hazardous situations affecting boiler operation and operator safety.

Figure-5 shows two line pressure regulators shall be installed (PT). Additional pressure regulator is bounded in red. Each regulator keeps the pressure in a safe limit not exceeding the maximum pressure of the down- stream system. Any overpressure of the down-stream system might cause failure in both pressure regulators.

Additional pressure limiting or controlling device is not required if [7,8]:

- (1) The gas does not have materials that affect the operation or pressure regulators.
- (2) The gas source operating pressure is 60 psi (414 kPa).
- (3) The pressure regulator has characteristics such as:
  - (a) The maximum pipe connections to the regulator is not exceeding 2-in. nominal diameter.
  - (b) It has no external static or control piping.
  - (c) For the maximum gas pressure, if the port valve with has an orifice diameter smaller than manufacturer recommendations.
  - (d) The valve base is made of resisting material against abrasion, impurities and deformation caused because of the gas pressure.

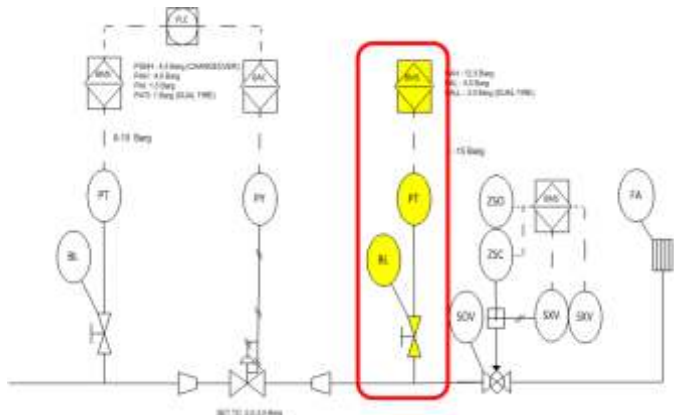


Figure 5. Two line pressure regulator for gas skid

**Pressure regulator Devices:**

Listed below pressure regulators could be used to control gas pressure in the piping system [6].

- (1) A series regulator installed upstream from the service or line regulator (additional pressure regulator bounded in red shown in figure-5).
- (2) A monitoring regulator connected in series with the line pressure regulator (PT).
- (3) Limit switch close/open (ZSC/ZSO) to operate the control valve responding to the received signal from BMS.
- (4) Automatic shut off valve connected in series with pressure regulator to shut off when the pressure of piping system exceeds manufacturer limits (SOV).
- (5) A liquid seal relief device opens at the desired pressure with high efficiency (FA).
- (6) Solenoid valve (SXV).

**Vents:**

The size of the vent device should be same or greater than the outer relief valve (FA) [9].

**A.2 Back Pressure**

Back pressure preventers and Protective devices should be installed before pressure regulators close to the equipment connected to compressed fluid as oil or supply system [6]. Gas and air combustion mixers do not require installation of back pressure preventers unless they are connected compressed air or oxygen at pressures of 5 psi (34 kPa) or more [7,9].

Figure-6 shows back pressure protective Devices which are installed before pressure regulator devices to protect equipment from damages that might be caused by back pressure of gas or supplied air and prevent it from returning to gas and air storages. Protective devices are:

- (1) Check valves (CH 062).
- (2) Three-way valves (shown in figure-6).
- (3) Reverse flow indicators controlling positive solenoid valves (SXV 062).
- (4) Normally closed air-actuated positive shutoff pressure regulators (pressure regulators shown in figure-5).

Solenoid valves (SXV) might affect the operation of the pressure relieving valve (FA), so it is required to install duplicate relief valves, each having enough capacity to protect the system as shown in figure-5 or three-way valve as shown in figure-6 so that only one device can be rendered inoperative at a time [6,9]. A gas shutoff valve shall be implemented upstream of each gas pressure regulator. If two gas pressure regulators are connected in series, a manual gas shutoff valve shall not be installed at the second regulator [8].

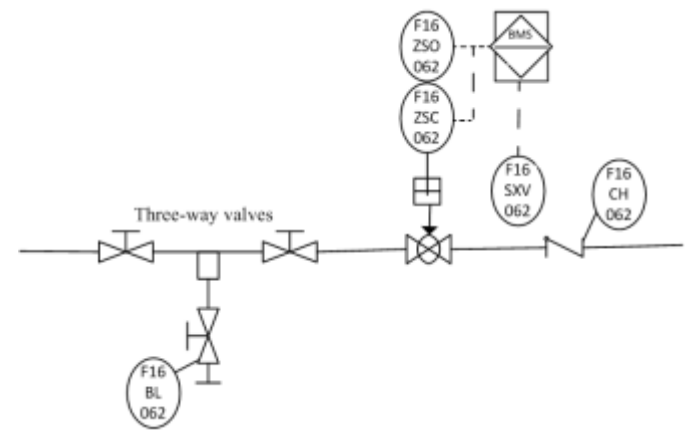


Figure 6. Back pressure protective system

**Low-pressure protective devices:**

Mechanical or diaphragm-operated or electrically operated low pressure shutoff valves shown in figure-5 (SOV).

**Other Safety Equipment:**

More safety equipment shall be used as manual reset valves (MV), high-temperature limit switches (ZSC/ZSO), shutoff valves (SOV), air-flow switches, door switches and gas valves [6].

**A.3 Flow Control Using Control Valve Sizing:**

Control valves are used to control flow, pressure temperature and fluid level by responding to signal received from the controller which compares the set point to the control variable (pressure, temperature, level and/or flow) which is provided by gauge sensor and monitoring elements. Control valves are controlled with petitioners such as electrical, hydraulic and pneumatic actuators using either 4-20 mA electric signal or 3-15 Psi. Fluid flow rate depends on the size of the control valve and the valve travel, as the travel is varied from 0 to 100 percent. Fluid flow characteristic refers to the characteristic observed during burner operation.

**Disadvantage of current design:**

It takes more than 30 minutes to ignite and run the burner. This time delay affects boiler operation and the quantity of the generated steam.

**Design Improvement:**

To improve fluid flow and operation speed, valve size shall be changed to match flow characteristic needed. For good fluid flow control, it is essential to select the correct size for the valve as well as the valve characteristic. Shown below an example for water valve sizing:

**Water Valve Sizing**

It is essential to determine the valve sizing in boiler burner for 600,000 pounds per hour water flow with no density consideration. A rule of thumb for pressure drop is one third of the pressure drop across the system for the pressure drop across the valve.

$Q = \text{gpm}$

SG = specific gravity

$\Delta P$  = pressure drop across valve

$C_v$  = Rate Capacitance Variable

$= \text{GPM} \sqrt{\text{SG} \div \Delta P}$

The conversion of pounds per hour is:

$600,000 \div (8.34 \times 60) = 1200 \text{ GPM}$

If the pump discharge pressure is 2000 psig and the drum pressure is 1400 psig, the differential pressure is:

$600 \div 3 = 200 \text{ psig.}$

$C_v = \text{GPM} \sqrt{\text{SG} \div \Delta P}$

$C_v = 1200 \times \sqrt{(1 \div 200)} = 84.84$

$C_v = 300 \times \sqrt{(1 \div 200)} = 14.14$

The lower pressure drop of 150 psi for a lower flow rate.

$C_v = 300 \times \sqrt{(1 \div 150)} = 24.5$

If the water temperature is 450°F, then the change in specific gravity must be considered. The specific gravity of water at 450°F is 0.827.

$C_v = 1200 \times \sqrt{(0.827 \div 200)} = 77.16$

$C_v = 300 \times \sqrt{(0.827 \div 200)} = 12.86$

Assume a lower pressure drop of 150 psi for a lower flow rate.

One fourth  $C_v = 300 \times \sqrt{(0.827 \div 150)} = 9.65$

Referring to equal percentages Table-3, a three or four inch valve can be used. If a three inch valve is selected, it is almost 100 percent open. A four inch valve should be selected and would have less line pressure drop. For best control, the  $C_v$  should be at 20 percent at the lowest flow and 80 percent at the highest flow rate.

TABLE III. EQUAL PERCENTAGES

| Valve Size | Rated Cv | 10   | 20   | 30   | 40   | 50   | 60   | 70   | 80   | 90   | 100 |
|------------|----------|------|------|------|------|------|------|------|------|------|-----|
| 3 inch     | 95       | 4.45 | 6.25 | 8.78 | 12.3 | 17.3 | 24.4 | 34.2 | 48.1 | 67.6 | 95  |
| 4 inch     | 190      | 8.9  | 12.5 | 17.6 | 24.7 | 34.7 | 48.7 | 68.5 | 96.2 | 135  | 190 |
| 8 inch     | 420      | 19.7 | 27.6 | 38.8 | 54.6 | 76.7 | 108  | 151  | 213  | 299  | 420 |
| 10 inch*   | 420      | 19.7 | 27.6 | 38.8 | 54.6 | 76.7 | 108  | 151  | 213  | 299  | 420 |
| 10 inch    | 735      | 34.4 | 48.4 | 68   | 95.5 | 134  | 189  | 265  | 372  | 546  | 735 |

\*10 inch valve with reduced trim note the Cv is the same as the eight inch valve.

For more information, reference to ANSI/ISA -75.01.01-2002

**B. Safety:**

Furnace or boiler burner is a combustion chamber that releases huge amount of heat. It also works as heat exchanger as it transfers the released heat to the header system (water) to create steam. Monitoring the control of burner temperature, pressure, time and turbulence is required to maintain the combustion process stable.

**Disadvantage of current design:**

Combustion process should be controlled in a safe way by monitoring flame presence of the burners with flame detectors (BE915) as shown in figure-7. Some hazards can occur through a healthy burner using single flame detector due to a failure or fault within the flame detector. In this case, flame detector might fail to detect the flame presence of the burner and fail to initiate alarm and to trip the combustion process. Moreover, it might launch a master fuel trip condition while the burner is still operating in a healthy way. This hazard might cause damage to the operators, combustion process, equipment, the environment and/or loss of money.

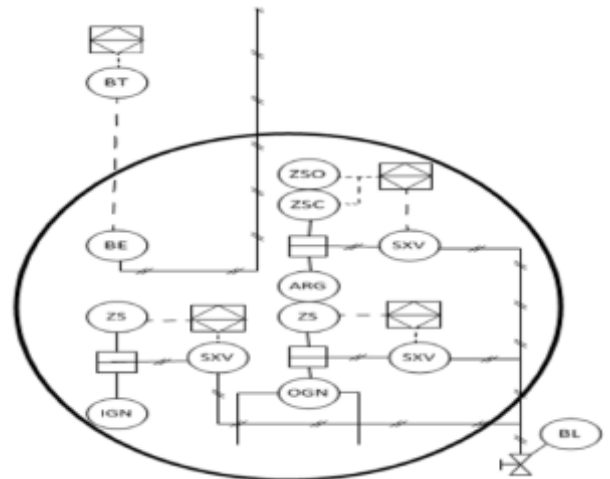


Figure 7. Single burner with single flame detector

**Design Improvement:**

Another aspect of boiler control is the interlocking system which is a safety system used to monitor plant operation and trip the plant during any hazardous situation that might cause plant implosions or explosions and covers all those "yes-no" decisions related to equipment operation. The goal is to keep the plant protected at all times with a safe complete monitoring system for burner pressure, temperature and air flow control. The best monitoring classifications described below are named on the basis of the number of unflawed interlock circuits (flame detectors BE915) necessary in order to remain operation safe:

2-0-0-2-Two out of two. This is not redundancy as damage or failure of a burner using single flame detector will cause an output tripping action but with using two flame detectors as shown in figure-8 both are required to detect burner flame and if both detectors initiate alarm, the boiler will trip. Any failure of single detector will not trip the operating equipment

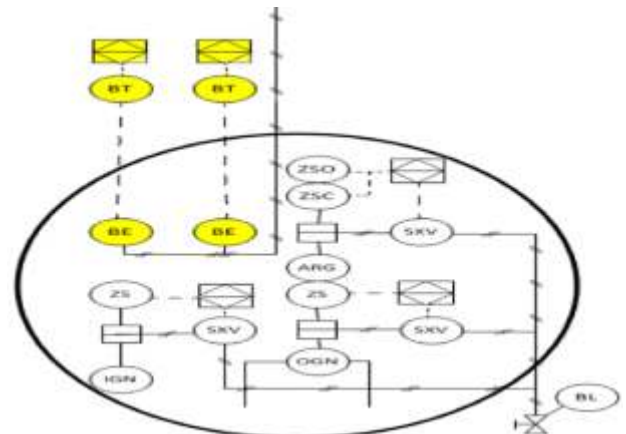


Figure 1. Single burner with two flame detectors

**A. Cost:**

**Oil and Atomizing Media Skid**

Oil and atomizing media skid describes the pipeline systems that deliver oil and atomizing media (air) from storage tanks to boiler burners to be mixed together for the combustion process. The pipeline contains gauge, control and safety elements such as control valves, limit switches closed/open and pressure, temperature and flow transmitters.

**Disadvantage of current design:**

Current design of oil and atomizing media skid has extra final elements which are used for safety or control such by handling or stopping the fluid flow of process media in a specified location such as isolation valves (BL302) with an average cost of \$500-600 (average cost in American market provided by vendors) and solenoid valves (SXV069) with an average cost of \$139.94 (average cost in American market provided by vendors) shown in figure-9. Those elements are installed in addition with other safety and control elements that can secure and control the process of fluid flow in a safe way such as control valves and limit switches close/open (ZSO/ZSC 065).

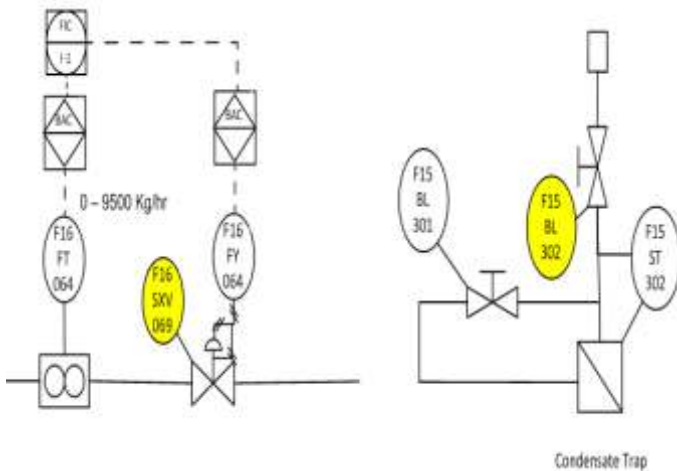


Figure 9. Additional Final Elements

Limit switch is a switch that controls an electrical circuit by opening and closing. If the switch is in closed position, current starts flowing to the connected device. If it is opened, the electrical current stops flowing. Installation of additional safety elements will increase plant size and plant and maintenance cost.

**Design Improvement:**

Control valves and limit switches are enough to control the process. By uninstalling and removing extra final elements (Isolation valve BL302 and Shut off valve SXV069), fluid flow of media process would be handled and controlled safely. Moreover, it would decrease plant size and the cost of removed elements as shown in figure-10.

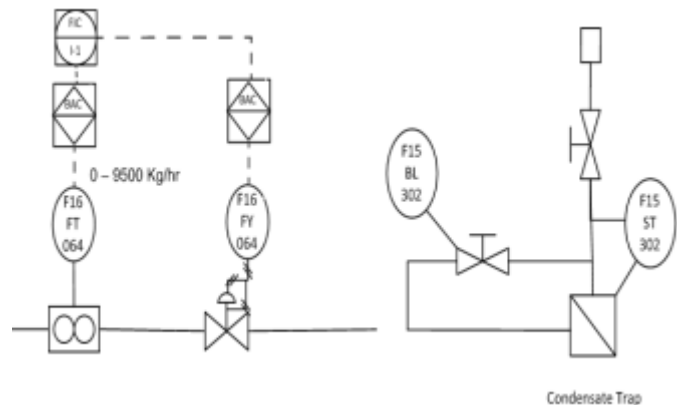


Figure 10. Removal of extra Final Elements

**D. Efficiency:**

Efficiency is a very important criterion in Boiler P&ID Design. Efficiency depends on fuel type either gas or oil. Current efficiency of gas fired steam boiler is about 70% and it is about 85% for oil fired boilers

(Efficiency percentage is identified by vendors recommending to use oil instead of gas). Higher moisture and wet content in the fuel reduces its efficiency.

The best basic method to calculate boiler efficiency is heat loss method by calculating heat input and heat losses. Boiler Efficiency is the ratio between output and input. Efficiency calculations stated below are based on gas fired boilers and were recommended by vendors to calculate efficiency of the system. The value of heat losses were obtained from the data sheets of the current system. To obtain superheated steam, boiler is operated with higher heating value (HHV) of temperature to get a very dry steam with zero moisture level. With lower heating value (LHV), boiler produces normal steam.

**D.1 Heat Losses with higher heating value (HHV):**

**1. Combustion heat losses:**

Combustion takes place to release huge amount of heat. Flue gases leave the burner with high temperature which is considered combustion heat losses.

HHV: Higher heating value

CP: Constant Pressure inside the burner

Tb: Temperature of flue gases before releasing

Ta: Temperature of flue gases inside the relief valve while releasing

**Combustion Heat Losses**

$$L_c = \text{Unit storage fuel} \times CP \times (T_b - T_a) \times 100 / \text{HHV}$$

$$= 13.5 \times 0.24 \times (303 - 81) \times 100 / 13102.36$$

$$= 5.42 \%$$

**2. Moisture losses:**

The fuel storage should be sealed with nitrogen to reduce moisture absorbs. Wet gases absorb more heat for combustion.

$$L_m = \text{Fuel Moisture} \times (1089 - T_a + 0.46 \times T_b) \times 100 / \text{HHV}$$

$$= 0.03 \times (1089 - 81 + 0.46 \times 303) \times 100 / 13102.36$$

$$= 0.259 \%$$

**3. Moisture losses inside the furnace:**

$$L_f = \text{Moisture Inside the furnace} \times (1089 - T_a + 0.46 \times T_g) \times 100 / \text{HHV}$$

$$= 0.371 \times (1089 - 81 + 0.46 \times 303) \times 100 / 13102.36$$

$$= 3.19 \%$$

**4. Atomizing media moisture losses :**

$$L_a = \text{Atomizing media moisture} \times CP \text{ of output (steam)} \times (T_g - T_a) \times 100 / \text{HHV}$$

$$= 0.0129 \times 12.89 \times 0.46 \times (303 - 81) \times 100 / 13102.36$$

$$= 0.14 \%$$

**5. Radiation Losses:**

Radiation losses depend on the type and the size of the boiler and the type of the used fuel. It happens when the boiler loses heat to the atmosphere. Referring to the American Boiler Manufacturers Association's (ABMA) standard radiation losses shown in table-8 to get approximate value of heat radiation losses for steam fired boilers with maximum output of 180 millions of Btu.

$$L_r = 0.4 \%$$

TABLE IV. ABMA RADIATION LOSSES

| Max output, millions of Btu | 100 % | 80 % | 60 % | 50 % | 40 % | 20 % |
|-----------------------------|-------|------|------|------|------|------|
| 10                          | 1.60  | 2.00 | 2.67 | 3.20 | 4.00 | 8.00 |
| 20                          | 1.05  | 1.31 | 1.75 | 2.10 | 2.62 | 5.25 |
| 30                          | 0.84  | 1.05 | 1.40 | 1.68 | 2.10 | 4.20 |
| 40                          | 0.73  | 0.91 | 1.22 | 1.46 | 1.82 | 3.65 |
| 50                          | 0.66  | 0.82 | 1.10 | 1.32 | 1.65 | 3.30 |
| 60                          | 0.62  | 0.78 | 1.03 | 1.24 | 1.55 | 3.10 |
| 70                          | 0.59  | 0.74 | 0.98 | 1.18 | 1.48 | 2.95 |
| 80                          | 0.56  | 0.70 | 0.93 | 1.12 | 1.40 | 2.80 |
| 90                          | 0.54  | 0.68 | 0.90 | 1.08 | 1.35 | 2.70 |
| 100                         | 0.52  | 0.65 | 0.87 | 1.04 | 1.30 | 2.60 |
| 120                         | 0.48  | 0.60 | 0.80 | 0.96 | 1.20 | 2.40 |
| 140                         | 0.45  | 0.56 | 0.75 | 0.90 | 1.12 | 2.25 |
| 160                         | 0.43  | 0.54 | 0.72 | 0.86 | 1.08 | 2.15 |
| 180                         | 0.40  | 0.50 | 0.67 | 0.80 | 1.00 | 2.00 |
| 200                         | 0.38  | 0.48 | 0.63 | 0.76 | 0.95 | 1.90 |

### 6. Vendor margin losses:

Some losses are not counted and always given by vendors called margin losses. Margin losses are because of incomplete combustion of fuel, heat loss in flue gasses...etc. It ranges from 0.5 to 1.5 % depends on fuel and boiler type.

Vendor margin given  $L_g = 1.5\%$ .

$$\begin{aligned} \text{Total Heat Losses} &= L_c + L_m + L_f + L_a + L_r + L_g \\ &= 5.42 + 0.259 + 3.19 + 0.14 + 0.4 + 1.5 \\ &= 10.909\% \end{aligned}$$

$$\begin{aligned} \text{Therefore, Efficiency of the boiler on HHV basis} &= 100 - \text{Total Losses} \\ &= 100 - 10.909 \\ &= 89.091\% \quad 89\% \end{aligned}$$

### D.2 Efficiency with lower heating value (LHV):

$$\begin{aligned} &= \text{HHV efficiency} \times \text{HHV} / \text{LHV} \\ &= 89.091 \times 13102.36 / 12691.8 \\ &= 91.973\% \quad 92\% \end{aligned}$$

With the new P&ID designs of gas fired steam boilers efficiency increases from 70% to 89% representing the lowest losses of heat during combustion process with higher and lower heating value.

## V. SYSTEM IMPLEMENTATION ADVANTAGES

This study provides P&ID designing analysis to reduce failures that can lead to hazardous scenarios and provides safe control for the boiler and keep it in a safe mood during any unstable condition. This analysis enables to identify those safety elements that should be implemented to avoid the possible consequences of failure on demand. The implementation of those safety control methods has some advantages [6]:

- 1) Insure high safety limits during operation.
- 2) Insure a Safe and complete boiler purging process.
- 3) Insure a safe start-up.
- 4) Insure a safe shutdown.
- 5) Demand safe combustion control system for proper fuel burnings and air flows.
- 6) Insure continues boiler operation with high safety interlocks satisfied.
- 7) Establish fuel trips during boiler operation.

The specification of safety requirements for boiler designs means what the safety function is intended to do. Moreover, NFPA standards require integrity requirements to create a safe boiler design with equipment fit for purpose [6]. The proper arrangement of boiler components and equipment achieves the process safety by the risk reduction [2]. The implementation of the safety control methods and boiler design requires additional safety components and equipment to be added to the boiler to operate the boiler in a safe way. This might has larger investment and operational cost but it demands boiler operation with high safety levels avoiding life, property and monetary losses [3].

## VI. CONCLUSION

Boiler is used to produce steam for generating electricity, heat and personal uses. Many hazards are affecting boiler operation process causing boiler implosions, operator injures and loss of life. An improvement of boiler P&ID designs could be done to avoid any hazards affecting operation process. By following safety control methods, boiler P&ID would include extra safety elements and sensors that make boiler operation much safer avoiding any hazardous situation. Current results obtained system efficiency improvement from 70% to 89%. All control methods and boiler designs are based on several standards such as NFPA-85, ASME and ISA-77 published recently in order to implement safety control requirements for BMS systems. Future works might follow newer standards and safety regulations with upgraded safety system requirements and proper boiler designs as well as simulation software to get the highest efficiency of the con-

trol system. Moreover, with a proper arrangement and sizing of boiler components operation process becomes smoother and easy to be controlled with higher efficiency. The correct selection of safety equipment and boiler components has very important benefits to operation costs and boiler safety. Equipment selection has to be made in accordance to risk reduction.

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