Designs of Boiler Burner Management System

By

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CERTIFICATION OF APPROVAL

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Ahmed Mohamed Said Abou El Rish

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.

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CHAPTER 1

INTRODUCTION

1.1 Boiler Mechanism.

1.1.1) 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. A boiler is comprised of two basic systems (see figure 1). One system is the steam water system also called the waterside of the boiler. In the waterside, water is introduced and heated by transference through the water tubes converted to steam, and leaves the system as steam.

The other boiler system is the fuel air-flow gas system, also referred to as the fireside of the boiler. This system provides the heat that is transferred to the water. The inputs to the system are the fuel and air required to burn the fuel [1]. The fuel and air chamber is also referred to as the wind-box. The outputs are the flow gas and ash [2].

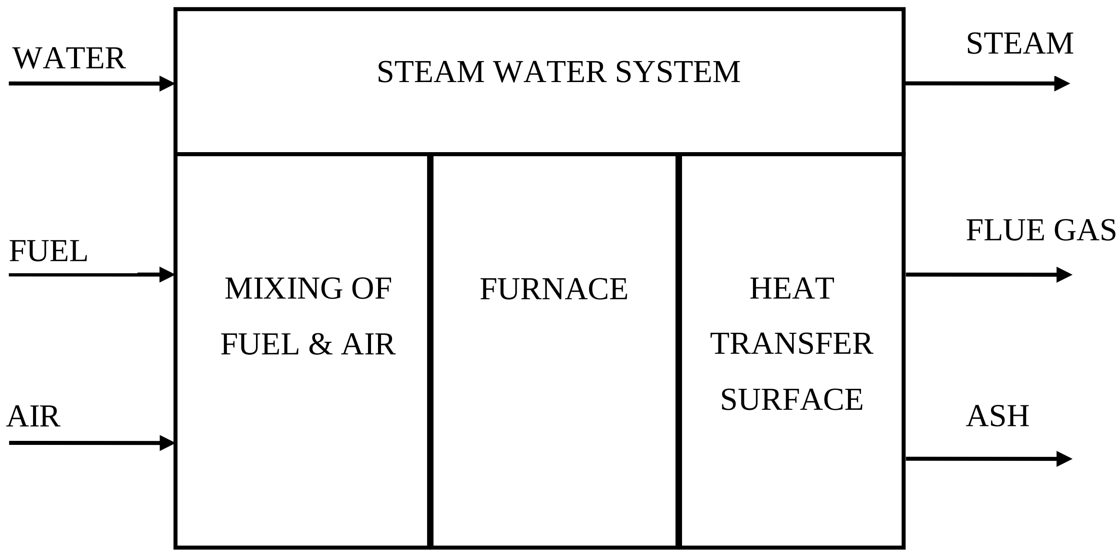

Figure 1 Boiler Basic Diagram [1]

1.1.2) Burner Management System (BMS):

The general term used for a safety system is burner management system (BMS). However, it may also be referred to as a combustion safeguard, burner/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].

The BMS is the system that monitors the fuel burning equipment during startup, shutdown, operation and transient conditions [1]. It is designed to present the status of all fuel burning equipment to the operator in a concise format. The BMS initiates a safe operating condition or shutdown procedure to prevent an explosion if an unsafe condition exists, thus protecting equipment from damage and people from injury or death. Figure- 2 shows burner management system monitoring the operation if the control valve and sends electric signal (4-20 mA) to limit switches (ZSO-ZSC) and solenoid valves (SXV) to shut off the valve and trip fluid flow during hazardous situation. The basic process control system (BPCS) modulates fuel and air input to the boiler in response to load variations. The burner management system essentially is an on/off control system that permits firing of a boiler at any load when safe conditions exist. If an unsafe condition occurs, the BMS automatically shuts off fuel or causes the boiler to go to a safe state. 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].

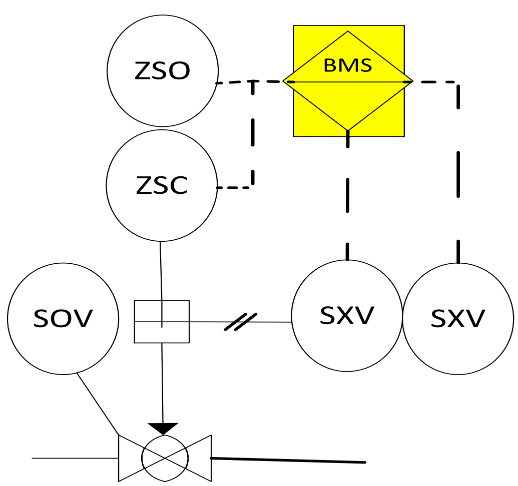

Figure 2 Burner Management System

1.1.3) NFPA Code:

The NFPA 85 is a Boiler and Combustion Systems Hazards Code 2011 Edition [6]. The NFPA 85 Code applies to single burner boilers; multiple burner boilers; stokers; atmospheric fluidized-bed boilers with a fuel input rating of 3.7 MW (12.5 million Btu/hr) or greater; pulverized fuel systems; and fired or unfired steam generators used to recover heat from combustion turbines (heat recovery steam generators, HRSG) [2,6].

The purpose of the Code is to ensure safe operation and to prevent uncontrolled fires, explosions, and implosions in equipment. The Code establishes minimum requirements for the design, installation, operation, training, and maintenance of boilers, pulverized fuel systems, HRSGs, and their systems for fuel burning, air supply and combustion products removal. The Code requires the coordination of operating procedures, control systems, interlocks, and structural design [3]. The most common contributor to boiler explosions is human error. Some hazards are very dangerous and might cause explosions or loss of life and a master fuel trip (MFT) is required to trip the fuel and close all fuel valves [6].

1.2 Problem Statement

Boiler Hazards:

Boiler operation and steam production has many hazardous situations and many risks affect safety requirements. Some of those hazards might cause boiler explosions that lead to injuries, life and property loss.

Boiler explosions typically occur during the period of lighting off the boiler. The absence of safety components and control elements such as flame detectors, pressure regulators and flow controllers would increase the probability of having boiler explosions and implosions. Moreover, the arrangement of boiler components has a great effect on the stability of the operation. The main cause of boiler explosions is the improper arrangement of boiler components such as control valves, pressure gauge, shut off valves … etc. which might cause failure to trip the fuel during any hazardous situation.

The magnitude and intensity of the explosion will depend on both the relative quantity of combustibles that has accumulated and the proportion of air that is mixed therewith at the moment of ignition. Table 1 summarizes some boiler explosions [11].

Table 1 BOILER EXPLOSIONS [11]

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

Some Boiler hazards and emergency situations [6,7,8,9]:

(1) Loss of any ID or FD fan required to sustain combustion.

(2) Furnace pressure in excess of the design operating pressure by a value recommended by the manufacturer.

(3) Insufficient drum level.

(4) Loss of boiler circulation pumps or flow, if applicable.

(5) Total airflow decrease below the purge rate by 5 percent of the full load airflow

(6) Temperature falling below the specified value when the main fuel is being admitted and no warm-up burner is established.

(7) All fuel inputs zero and temperature not adequate once any fuel has been admitted to the unit

To combat the boiler explosion hazard, a proper arrangement of boiler components was developed by creating perfect P&ID designs for 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].

1.3 Objectives

The objective of the project is to combat the boiler explosion hazard by editing and improving the P&ID controllers of the boiler system with a proper arrangement of boiler components to reduce the hazard to a minimum by creating accurate piping and instrumentation diagram (P&ID controller designs) for boiler burner management system [2]. The new P&IDs provide a safe instrumented system to protect possible hazardous conditions such as; supervising safety limits and flame presence during operation and insuring a complete pre-purge of boiler. It verifies the requirements of NFPA 85 to be checked on Boiler Burner Management System and all safety requirements were developed.

1.4 Scope of study

- Reviewing previous studies on making and editing P&ID controller.
- Reviewing non-efficient parts of the current designs.
- Designing new P&ID controller designs for the boiler.
- Testing new designs
- Establishing boiler efficiency calculations.

CHAPTER 2:

LITERATURE REVIEW

2.1 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) [20]. As shown in figure-3, 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
- Electrical data such as tracing and motor drives
- Interlocks
- Annunciation inputs
- Computer control system inputs
- Instruments and control loops

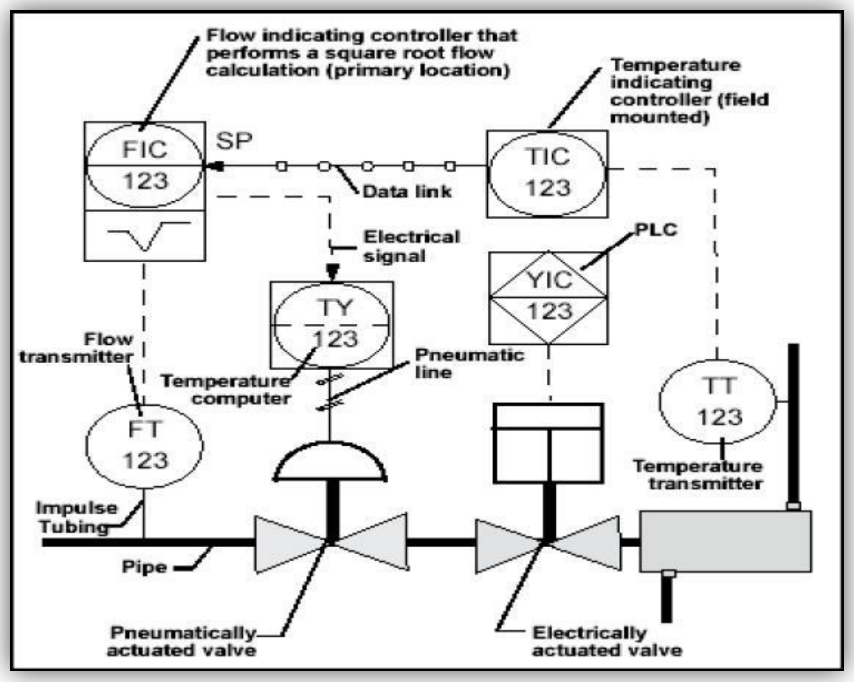

Figure 3 P&ID with Identifications [6]

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

2.2 *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].

The emphasis will be on high pressure (above 15 psi) steam boilers. This study is concentrated on the aspects of boiler control such as startup, shutdown, flame monitoring and safety interlock system aspects [1].

Boiler control was improved by performing the modulating actions of the control using analog equipment. The start-up, shutdown procedures and safety interlock system could are controlled in a digital way. The development of microprocessor-based distributed digital control has improved the control methods and equipment by integrating both two boiler control functions into one digital control system [1,6]. Most of industrial fields now are using new control methods with digital control systems.

Abouelrish and Soetjahjo proposed “NFPA 85 compliances of BMS” which states several solutions for some boiler hazards affecting boiler operation and operator safety. By following those methods, boiler could be controller within any hazardous condition and supplies continuous amount of steam with the lowest cost of boiler inputs. Some of those control methods shown below:

1- Oil Fuel Trips (OFT):

Hazard: Oil header pressure high during start up process

Figure-4 shows the suggested Control Methods in a logic sequence form:

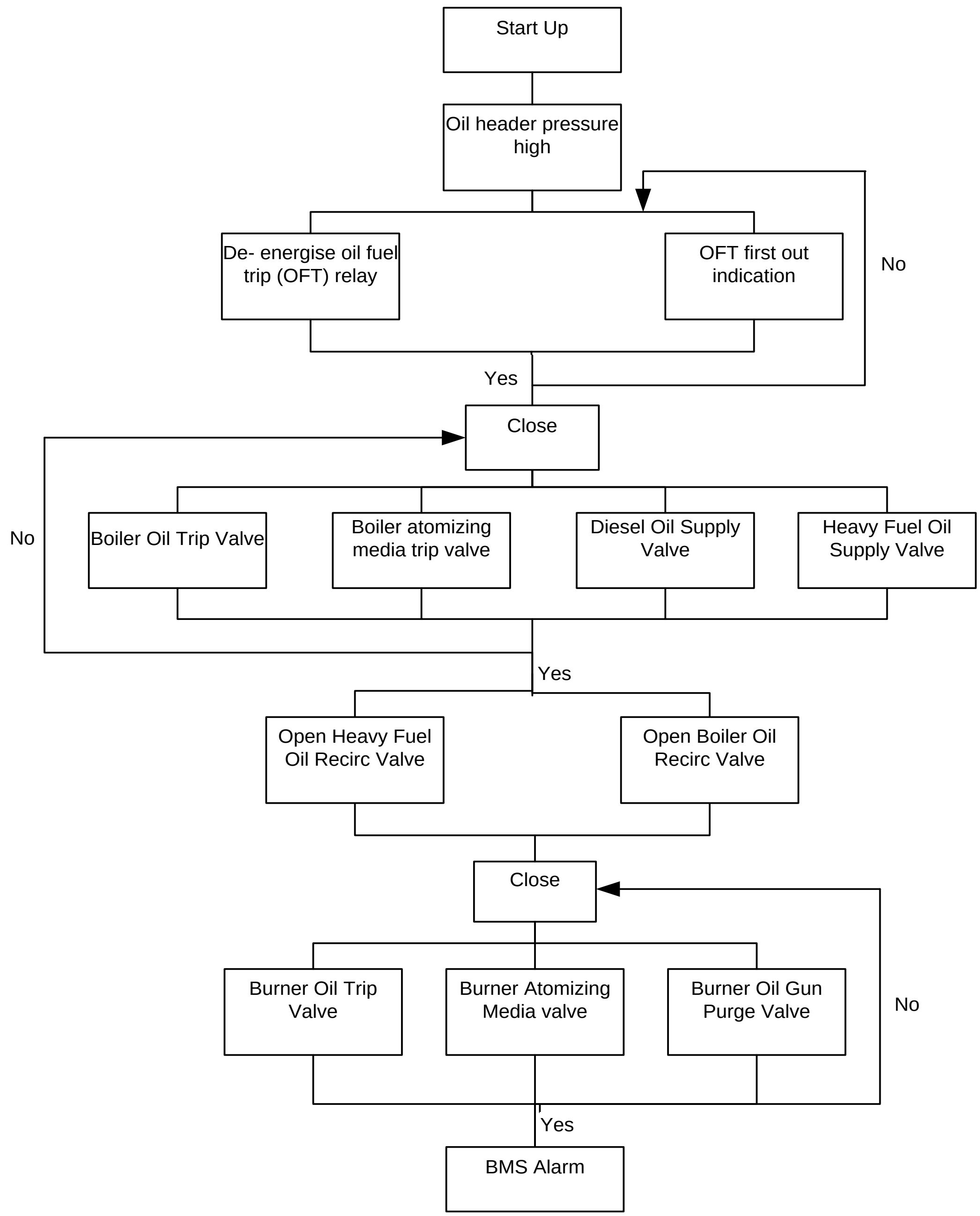

Figure 4 Oil Header Pressure High During Start-up [12]

2- Master Fuel Trips (MFT):

Hazard: Loss of all flame

Suggested Control Methods:

1) De-energise MFT relay.
2) MFT first out indication.
3) De-energise oil fuel trip (OFT) relay.
4) OFT first out indication.
5) Close boiler oil trip valve.
6) Close Boiler atomising media trip valve.
7) Close diesel oil supply valve.
8) Close heavy fuel oil supply valve.
9) Open heavy fuel oil recirc valve.
10) Open boiler oil recirc valve.
11) De-energise gas fuel trip (GFT) relay.
12) GFT first out indication.
13) Close supply gas trip valve.
14) Open supply gas vent valve.
15) Close boiler gas trip valve.
16) Open boiler gas vent valve.
17) Close burner oil trip valve.
18) Close burner atomising media valve.
19) Close burner oil gun purge valve.
20) Close burner gas trip valve.
21) Block N2 burner purge.
22) Hold forced draft (FD) fan vane position constant.
23) Burner management system (BMS) alarm.

Gilman proposed his book "Boiler Control System Engineering" states the characteristics and sizing of boiler control elements [3]. It states important information about boiler control which is useful for any one deals with boilers such as utilities managers, power plant managers, controls systems engineers, maintenance technicians and operators [6]. The study covers water tube boilers with Induced Draft (ID) and Forced Draft (FD) fan(s). It states engineering efficient control methods and the setup of the various control functions [3,6].

Table 2 Some Efficient Boiler Control Methods [7]

Item	Safety	Reason
Air Purge	For boiler start up, the air blower should provide amount of air 4 times furnace volume	For purging gases inside the boiler avoiding boiler explosions during start up
High Gas Pressure	A pressure switch shall be used to stop gas flow if the pressure exceeds the limit.	Failure in gas pressure control valve would allow excessive amount of gas to flow to the combustion chamber that might cause burner flame out and overheating.
Low Gas Pressure	A pressure switch could be used to stop gas flow if the pressure is too low.	With low gas pressure, the burner could go out causing explosion.
Low Flame Strength	By using a flame detector, burner would be tripped if the flame is weak or burner flame out.	If the flame goes weak or burner flame out, gas would keep flowing to boiler burners increasing in volume and pressure that might cause boiler explosion.
Air Blower Failure	A switch trips the burner if air blower is not operating.	If the air blower is not operating, the burner would be out of service.
Low Atomizing Media Flow	By using a pressure switch, burner, would be tripped if the atomizing media pressure gets too low.	If the atomizing media flow (air) is too low, the flame would be weaker or burner and the gas would keep flowing.

CHAPTER 3:

METHODOLOGY

3.1 Research Methodology:

Before implementing system designs, a research was made on boiler mechanism, control of boilers, boiler hazards and international control standards and safety regulations that describe boiler design, installation operation and maintenance such as:

- NFPA 85 – National Fire Protection Association
- ANSI – American National Standards Institute
- ASME – American Society of Mechanical Engineers
- ISA 77 – International Society of Automation

There are many techniques used to design the P&ID controller designs of the boiler and test them. These techniques are summarized into the below methodologies:

3.1.1 Reviewing current P&ID designs:

To modify the current design and make the operation of the boiler much safer and smoother, current design were reviewed to find out non-efficient parts that affect operation speed, safety and control.

3.1.2 Laboratory Designs:

After reviewing current designs and finding out the weak points of each pipeline such as absence of sensors or final elements, new designs were established with improvements on non-efficient parts of the current industrial ones. The new designs are following NFPA, ISA, ASME and other control standards and safety regulations. Different types of software were used to designs the system of the boiler and to achieve aforementioned objectives such as "MICROSOFT VISIO" as shown in figure-5.

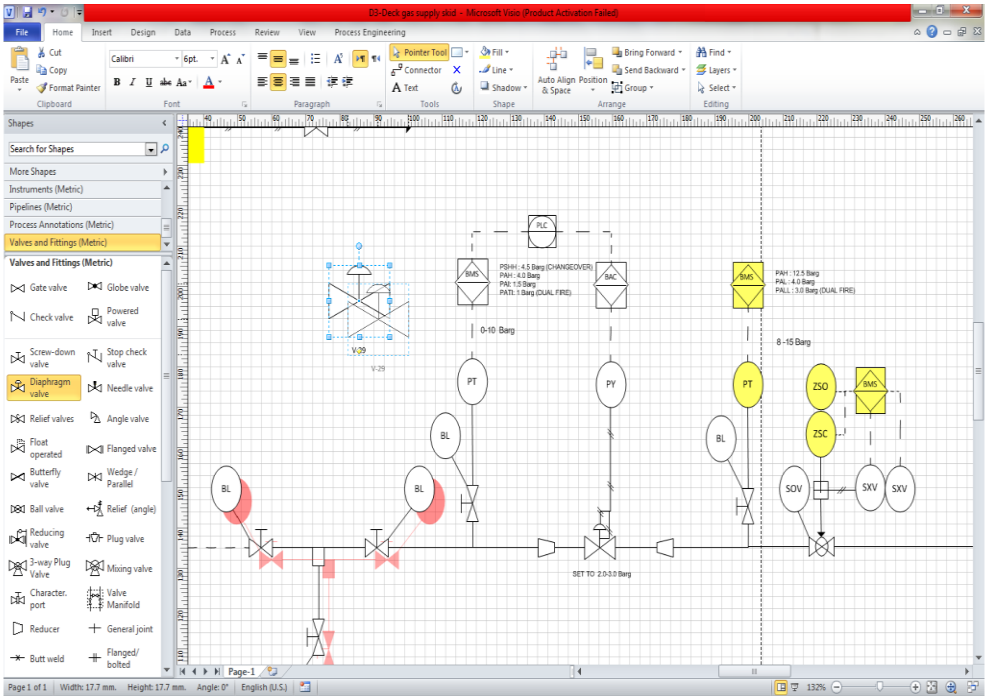

Figure 5 MICROSOFT VISIO Designing

3.1.3 *Comparing field data:*

Field data was compared with the results of the project to verify and approve the improvements were made on the current designs and to ensure that the system is controllable in a safe way.

3.2 Resources

The requirements needed to establish the P&ID designs are:

- NFPA 85 code and ISA 77.
- Instrumentation Design Software: MICROSOFT VISIO

Table 3 SOFTWARE List

Name	Description
MICROSOFT VISIO	A scientific designing, diagramming and vector graphics application which is a part of Microsoft Office suite.

3.3 Work Schedule:

The project was planned on two semesters. The first semester is to make a research on boiler mechanism, control of boilers, boiler hazards and international control standards and to find the suitable software to be used for implementing the new P&ID designs and to achieve the designs of oil, gas and atomizing media skid. The second semester is to continue P&ID designing and compare the new designs with the old one. Moreover, it is to improve boiler control system by finding the best valve sizing for each pipeline of the boiler and to calculate the system efficiency using heat losses efficiency equations.

Table 4 Gantt chart

Number of weeks	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
Research Work																												
Reviewing Current P&ID Designs																												
Designing P&ID Controller																												
Control Valve Sizing																												
Design Work Continues																												
Comparing Old and New Designs																												
Calculating System Efficiency																												
Paper Work and Final Report																												

Table 5 Key milestones

Number of weeks	6	9	13	22	25	26	27	28
Extended Proposal								
Proposal defense								
Draft Report								
Interim Report								
Progress Report								
Pre-EDX								
Draft Report								
Final Report								
Technical Report								
VIVA								

3.4 *Flowchart:*

The proposed system is described in the flowchart shown in figure-6:

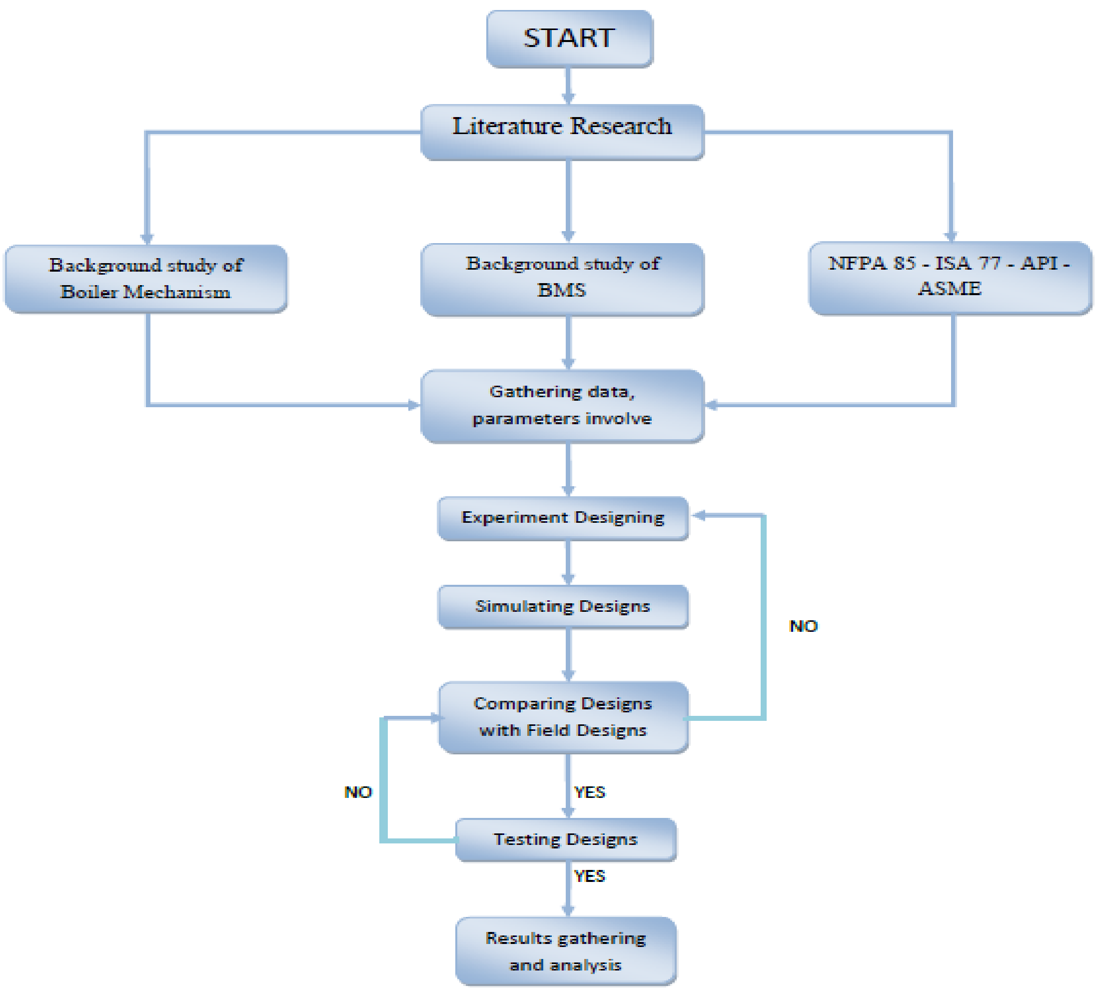

Figure 6 Flowchart

CHAPTER 4:

Discussion & Results

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. This is shown in the improvements were done on oil, gas, atomizing media skid and burners designs shown in Appendix-I.

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 as shown in table-6.

Table 6 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)

P&ID Designing Parameters:

4.1 Control.

4.1.1 Pressure Control:

4.1.1.1 Overpressure:

Disadvantage of current design:

Fluid flowing inside a pipeline such as oil, gas and atomizing media skid should be controlled with a specified pressure limit provided by manufacturer of the system with pressure regulator device as shown in figure-7. 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 manufacturer 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.

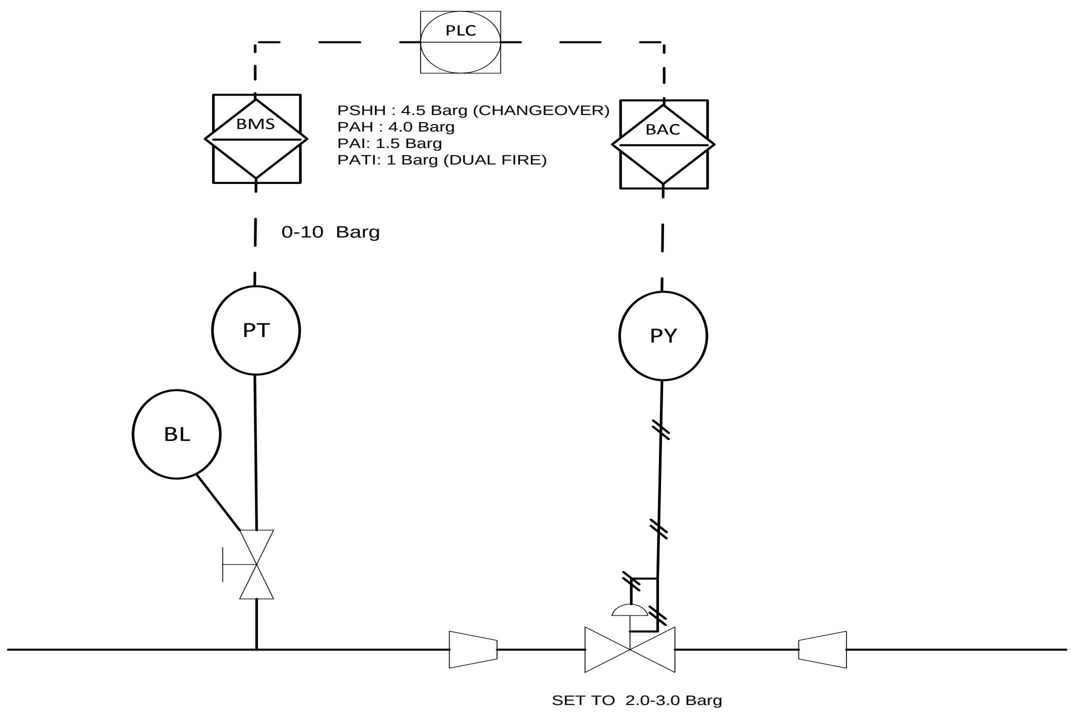

Figure 7 Single line pressure regulator for gas skid

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-8 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) or less.

(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.

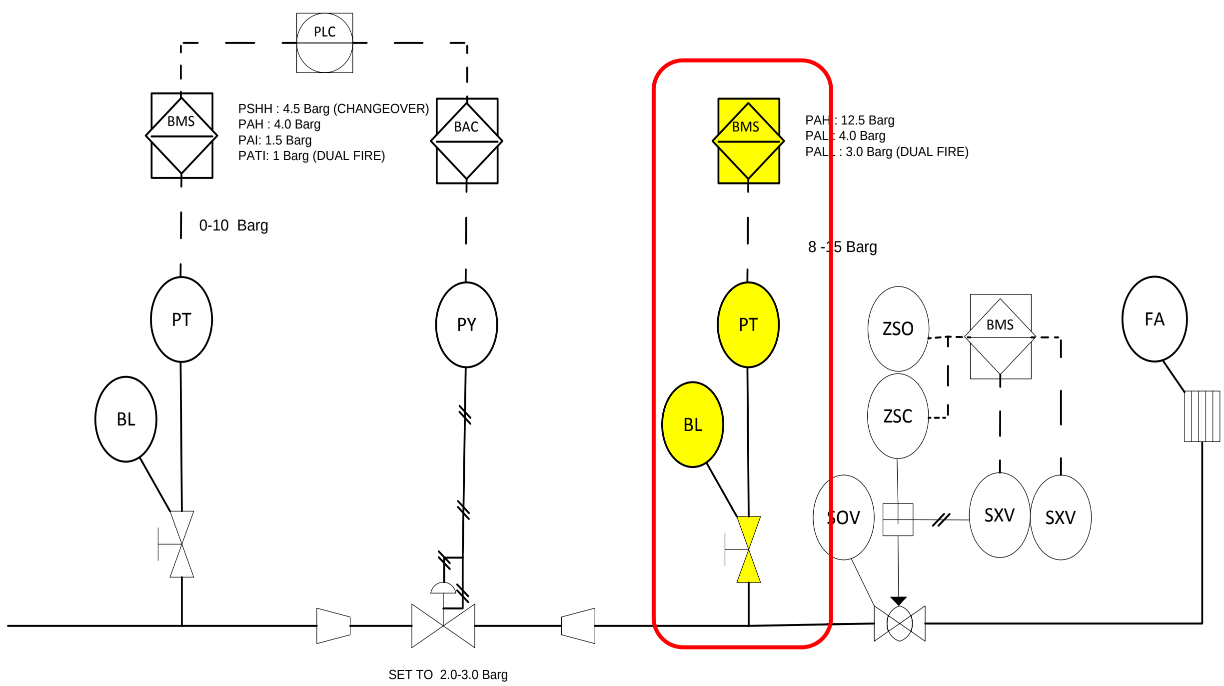

Figure 8 Two line pressure regulator for gas skid

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-8).

(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].

4.1.1.2 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-9 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-9).

(3) Reverse flow indicators controlling positive solenoid valves (SXV 062) .

(4) Normally closed air-actuated positive shutoff pressure regulators (pressure regulators shown in figure-8) .

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-8 or three-way valve as shown in figure-9 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].

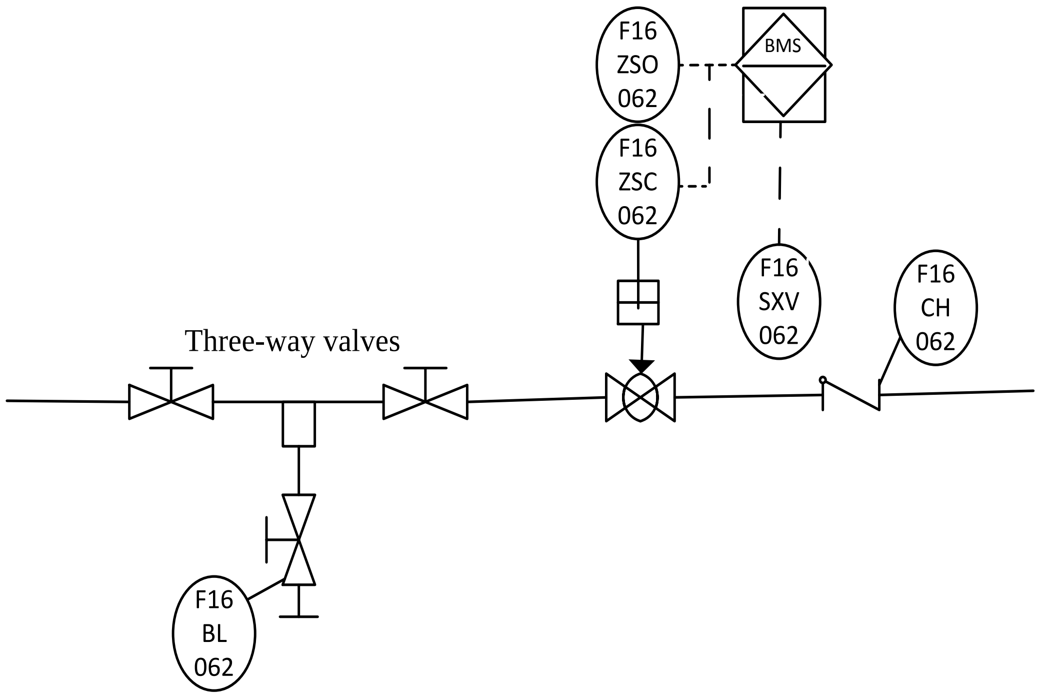

Figure 9 Back pressure protective system

Low-Pressure Protection

A low-pressure protective device should be implemented between the meter and the gas utilization equipment as gas compressors might produce a vacuum causing dangerous reduction in gas pressure.

Low-pressure protective devices:

Mechanical or diaphragm-operated or electrically operated low pressure shutoff valves shown in figure-8 (SOV).

Other Safety Equipment:

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

4.1.2 Flow Control.

4.1.2.1 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.

Improvement

To improve fluid flow and operation speed, valve size shall be changed following Flow Equations for Sizing Control Valves standard (ANSI/ISA-75.01.01) 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. Analyses of valve sizing and selection processes are shown below [13].

Recommended Velocities for burner fluids:

Maximum operating condition values:

- Liquids:

$$< 10 \text{ m/s} < 33 \text{ ft/s}$$

- Air:

$$< 1/3 \text{ MA (Mach)}$$
$$= 1/3 \times (330 \text{ m/s})$$
$$< 110 \text{ m/s} < 360 \text{ ft/s}$$

- Dry Gases and Steam:

<110 m/s < 360 ft/s

- Flashing Liquids:

< 60 m/s < 196 ft/s

Control Valve Sizing Calculations:

1) 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 = gpm

SG = specific gravity

ΔP = pressure drop across valve

Cv = Rate Capacity Variable = GPM ($\sqrt{}$ SG ÷ ΔP)

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:

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

$$Cv = GPM \sqrt{(SG \div \Delta P)}$$

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

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

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

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

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.

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

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

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

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

Referring to table-7 equal percentages of rate capacity variable Cv, 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 Cv value should be 20 percent at the lowest flow and 80 percent at the highest flow rate.

At 60°F water temperature, the Cv is 84.84 and at 450°F, the Cv is 77.16.

2) Steam Valve:

The calculations for 300,000 pounds per hour steam flow at 1000 psi and 800°F would be:

The equation is:

$$Cv = pph / 63 \times \sqrt{(\Delta P \div V)}$$

pph = pounds per hour

V = specific volume

ΔP = differential pressure across the valve

If a 400 psi system pressure drop and one third across the valve, the valve pressure drop would be 133 psi.

The specific volume for steam at 800°F superheated steam at 1000 psi is 0.6875.

$$Cv = 300{,}000 / 63 \times \sqrt{(133 \div 0.6875)}$$

$$\sqrt{133} \div 0.6875 = 13.9$$

$$Cv = 300000 \div (63 \times 13.9) = 300000 \div 876 = 684$$

Referring to table-7 equal percentages of rate capacity variable Cv, either an eight inch valve or a ten inch valve with reduced trim could be used.

3) Gas Valve Sizing:

This gas valve sizing is based on 100,000 SCFH. The 460 is degrees.

$$Cv = SCFH \times \sqrt{(460 + F°)}\ SG \div 1360 \times \sqrt{(P1 \times \Delta P)}$$

$$Cv = 100{,}000\ (0.6)\ \sqrt{(460 + 70°\ F)} \div 1360 \times \sqrt{(30 \times 10)}$$

$$Cv = 100{,}000\ (0.6)\ \sqrt{530} \div 1360 \times \sqrt{300}$$

$$Cv = 100{,}000 \times 0.6 \times 23.02 \div 1360 \times 17.32$$

$$Cv = 100{,}000 \times 13.8 \div 23555.2 = 58.59$$

Referring to table-7 equal percentages of rate capacity variable Cv, A three inch valve can be used.

Table 7 Equal Percentages [13]

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

4.2 Safety.

4.2.1 Boiler Burners:

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:

- Safety:

Combustion process should be controlled in a safe way by monitoring flame presence of the burners with flame detectors (BE915) as shown is figure-10. 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.

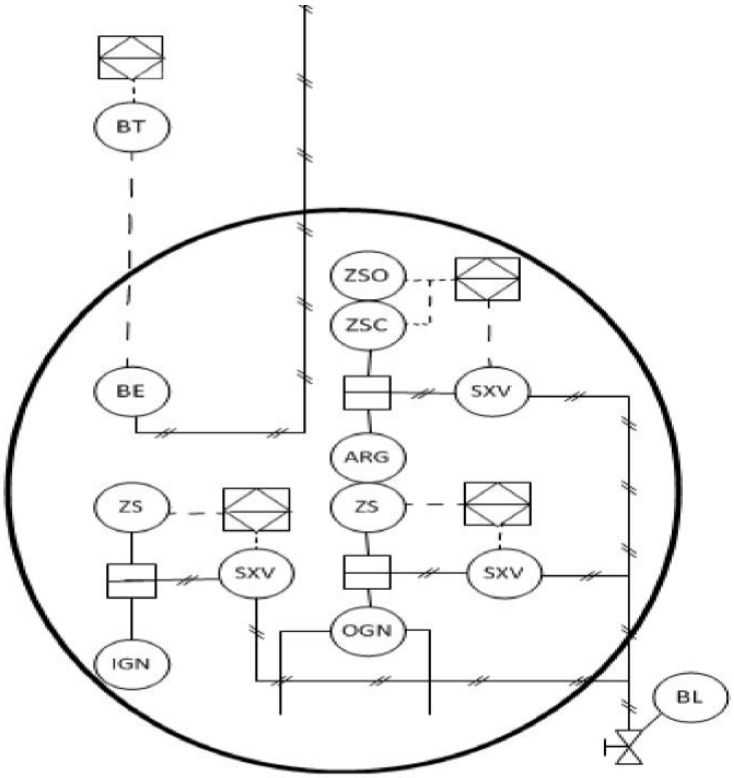

Figure 10 Single burner with single flame detector

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-11 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

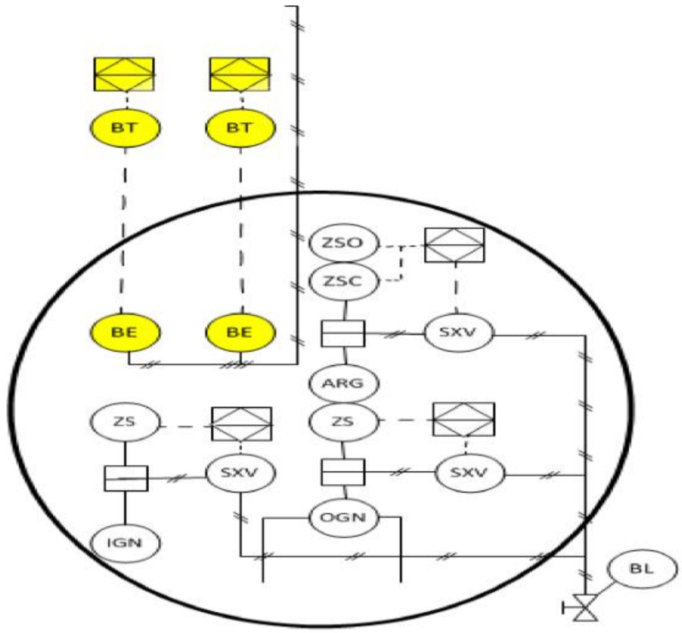

Figure 11 Single burner with two flame detectors

2-0-0-3-Two out of three. The triple redundancy system which is the most safe interlock system suits the plant. The output of two out of three flame detectors must agree to hold in a circuit in monitoring temperature control. If two out of three agree to trip, master fuel trip action will be initiated protecting burner equipment as shown in figure-12. Any failure of single detector will not trip the operating equipment. A maximum of two such failures will trip, just as a minimum of two good circuits will allow continued operation.

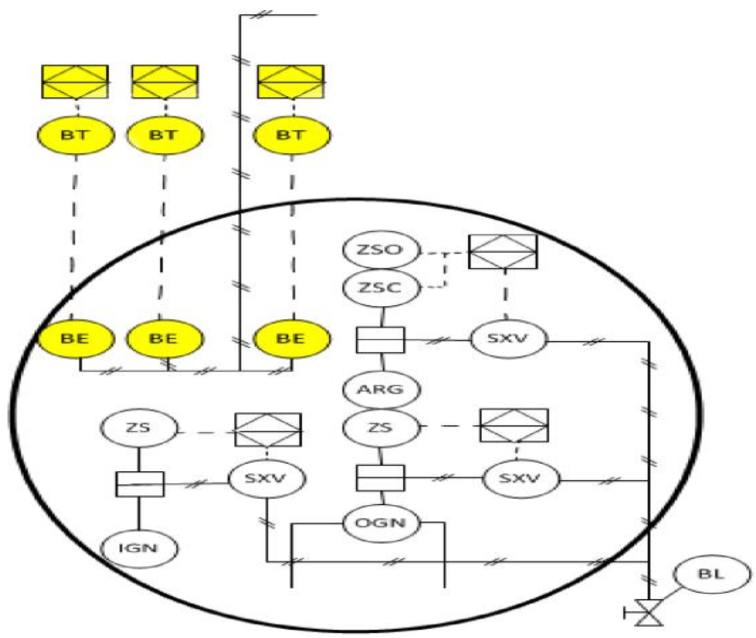

Figure 12 Single burner with three flame detectors

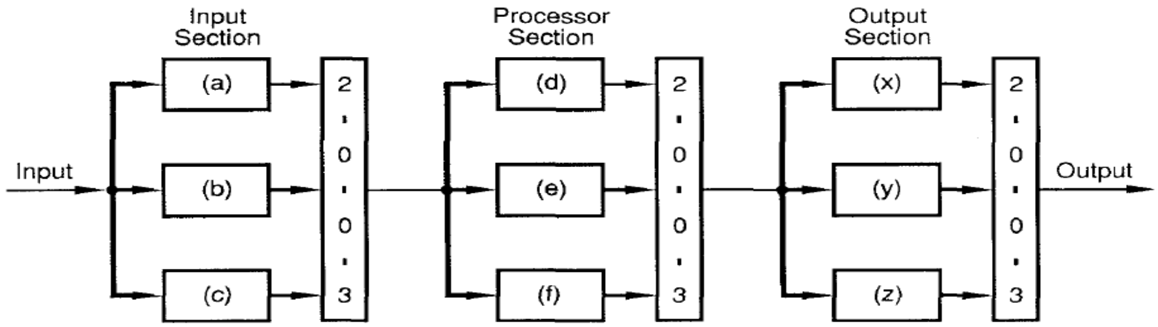

Figure 13 Two out of Three voting interlock circuitry [3]

Referring to figure-13, single failure of any element will not cause a burner trip but will cause failure of section circuit. Two faults will trip the burner if both faults are detecting the same burner. Three faults will cause a trip even if the third fault is in a different burner.

Main Burner:

1) To have a stable and perfect flame presence, the burner should direct the fuel and air into the furnace during operation period.
2) To determine the stability of flame presence, several tests shall be done.

   2.1) While performing these tests, the igniter shall be out of service.
   2.2) Boiler operation should not be affected by the transition of the fuel and air in the pipe line system.
   2.3) Manual device such as manual shutoff valve shall be secured in burned position.
   2.4) cleaning and maintenance shall be performed for atomizing medium system periodically.
   2.5) During the purging process of the atomizing medium system, all fans shall remain in service.
   2.6) Shutdown process is not allowed before cleaning the oil passage of the atomizing system into the furnace.

Self-Checking Flame Detector:

A master fuel trip shall be initiated automatically if the detector exhibits a self-check fault [6,8].

(A) By using two self-checking flame detectors for each burner, an alarm shall be initiated for absence of flame or the self-check failure of one detector and burner trip shall be conducted.

(B) If one detector is out of service, the other one shall trip the burner for losing flame or self-check fault.

Loss of flame in more than one burner is a hazardous situation that requires initiating master fuel trip. During flame loss situation, an alarm should be initiated as the fuel input does not ignite. Periodic tests shall be done on flame tripping to validate function efficiency [6,9].

4.3 Cost.

4.3.1 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:

- Cost:

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-14. 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).

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.

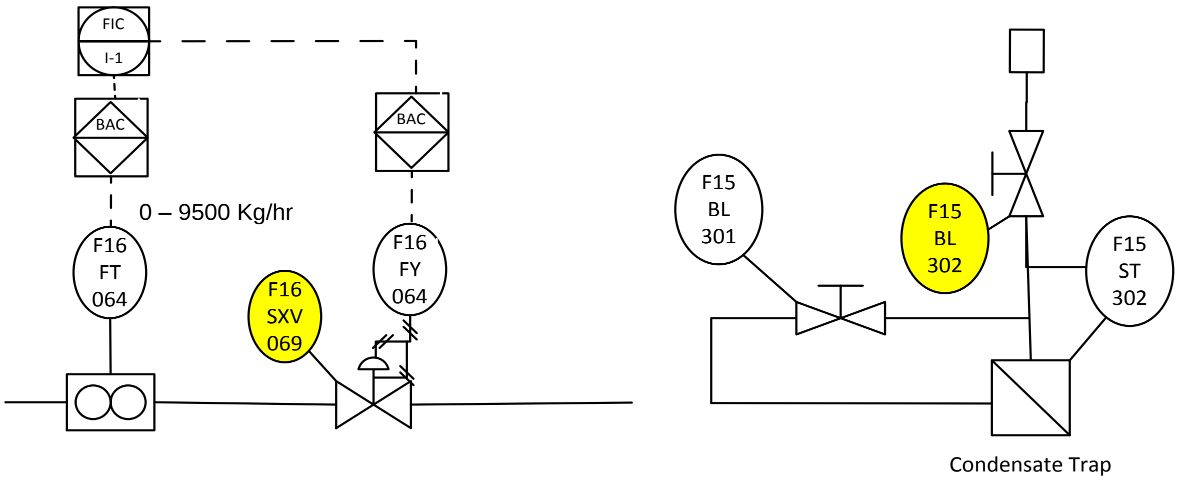

Figure 14 Additional Final Elements

Design Improvement:

Control valves and limit switches are enough to control the process. By uninstalling and removing extra final elements (Isolation valve BL302 and solenoid valves 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-15.

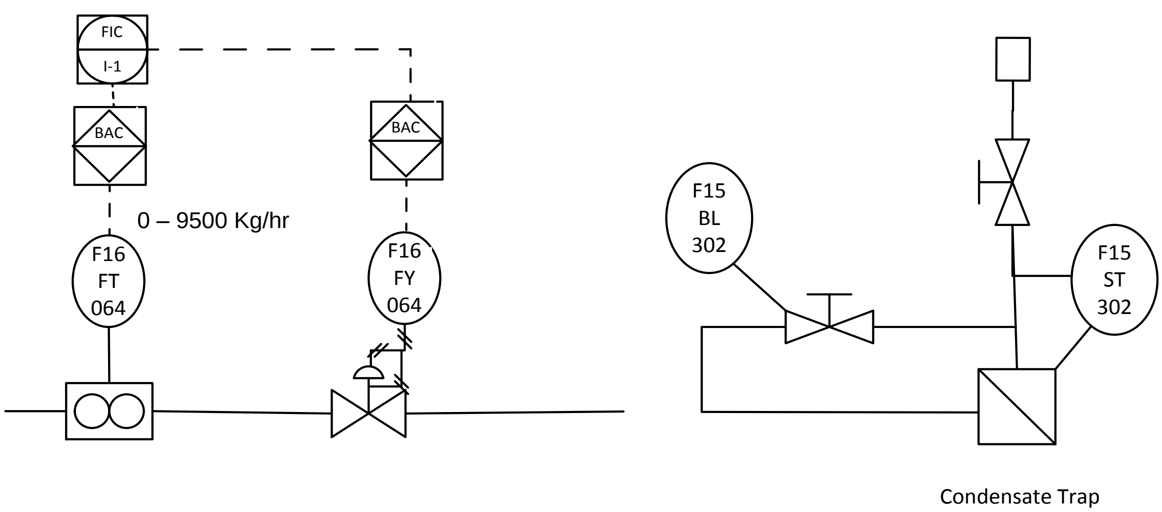

Figure 15 Removal of extra Final Elements

4.4 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 of6 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.

4.4.1 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, Lc = Unit storage fuel x CP x (Tb-Ta) x 100/HHV

= 13.5 x 0.24 x (303 -81) x 100 / 13102.36

= 5.42 %

2. Fuel skid moisture losses:

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

Lm = Fuel Moisture x (1089-Ta+0.46xTb)x100/HHV
= 0.03 x (1089 – 81 +0.46 x 303) x100 / 13102.36
= 0.259 %

3. Moisture losses inside the furnace:

Lf = Moisture Inside the furnace x (1089-Ta+0.46xTg) x 100/HHV
= 0.371 x (1089 – 81 +0.46 x 303) x 100 / 13102.36
= 3.19 %

4. Atomizing media moisture losses :

La = Atomizing media moisture x CP of output (steam) x (Tg-Ta) x 100/HHV
= 0.0129 x 12.89 x 0.46 x (303 - 81) x100 / 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.

Lr= 0.4 %.

Table 8 ABMA Radiation Losses [14]

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 Lg = 1.5%.

Total Heat Losses = Lc + Lm + Lf + La + Lr + Lg
= 5.42 + 0.259 + 3.19 +0.14 +0.4 + 1.5
= 10.909 %

Therefore, Efficiency of the boiler on HHV basis = 100 – Total Losses
= 100 – 10.909
= 89.091% ≈ 89 %

4.4.2 Efficiency with lower heating value (LHV):

= HHV efficiency x HHV / LHV

= 89.091 x 13102.36 /12691.8

= 91.973 % ≈ 92 %

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.

CHAPTER 5:

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. Efficiency of current designs improved 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 control 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.

Recommendations

Industrial Recommendations:

Industrial fields using oil/gas fired steam generators should follow the results of the project as well as international control standards and safety regulations to improve the control system and fulfil the minimum requirements of safety limits.

Academic Recommendations:

UTP automation and control laboratories should be supported with P&ID simulation software that makes P&ID design and simulation easier than before such as;

1- SCADA

2- ELECWORKS

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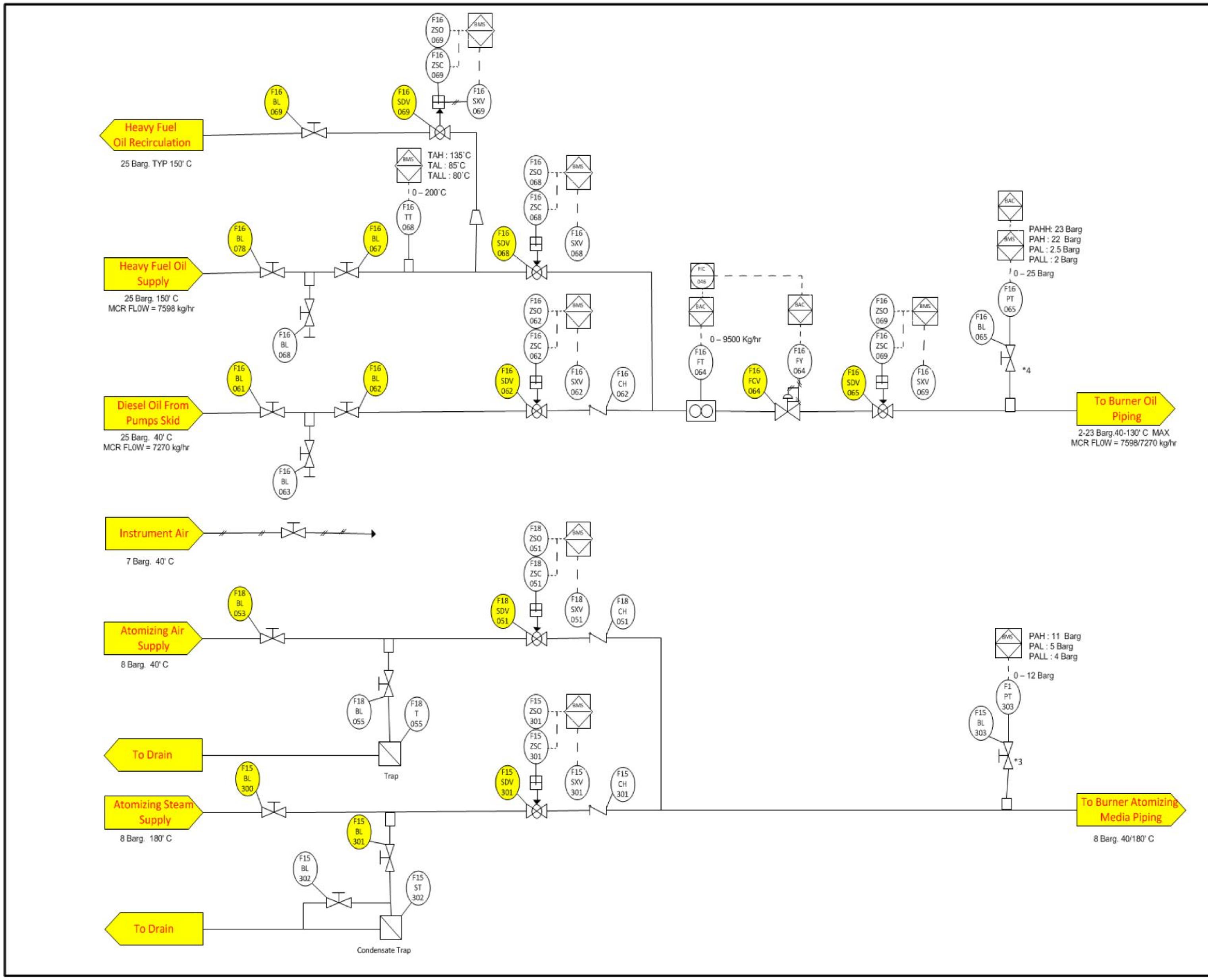
Appendices

Appendix-I

Results

Note:

Additional Control Elements are highlighted or bounded in red.



Notes:

1- All gauge pressure transmitters have block valves installed at the transmitter.
2- All differential pressure transmitters have block & equalising valves installed at the transmitter.
3- Block & bleed valves are used for isolation.
4- Double block & bleed valves are used for isolation.

Abbreviations:

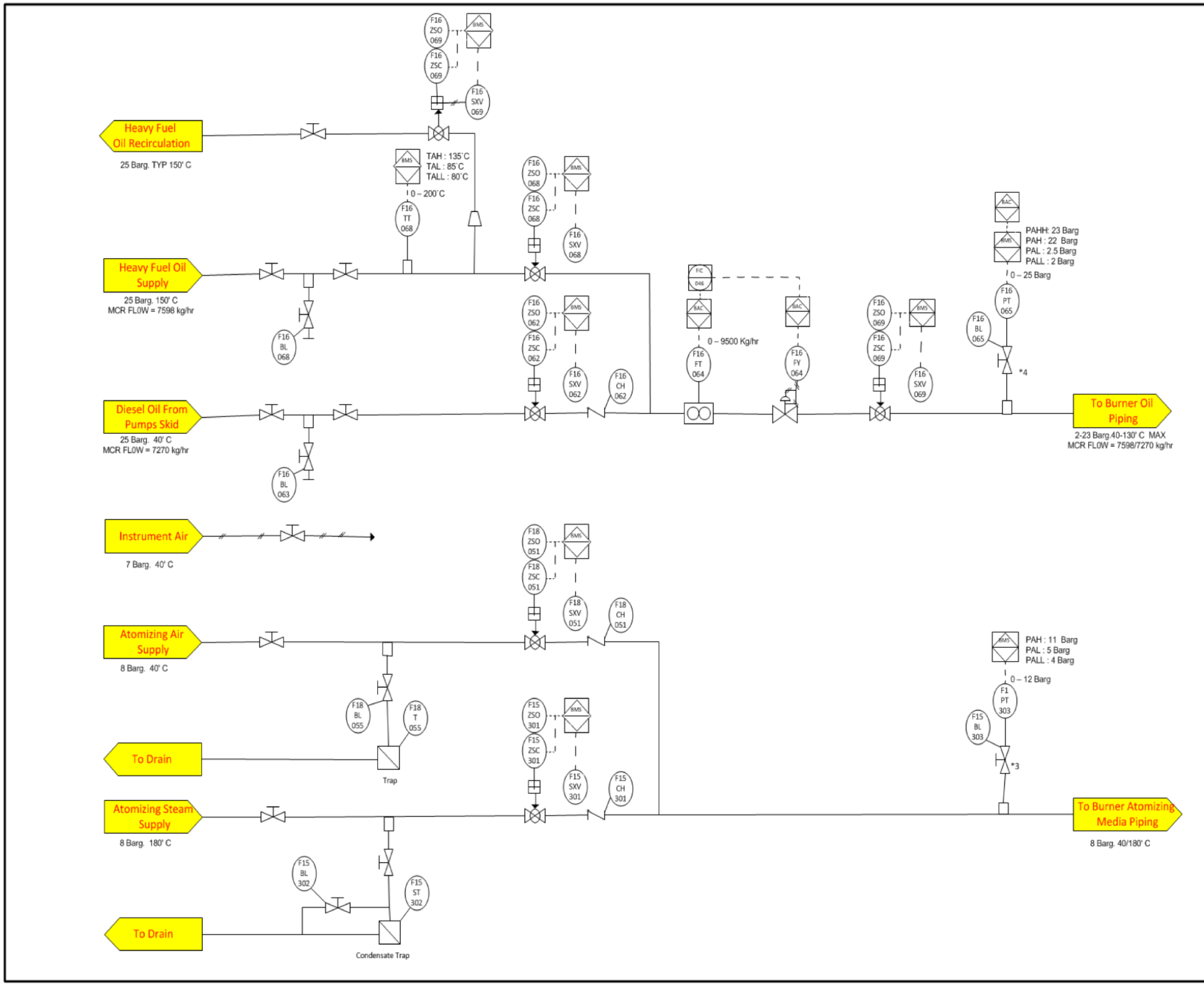
1- BAC: Boiler Automatic Control
2- BMS: Burner Management System
3- ZSC: Limit Switch - Closed
4- ZSO: Limit Switch - Open
5- SXV: Solenoid Valve
6- BL: Isolation Valve
7- TT: Temperature Transmitter
8- FIC: Fuel / Ignition Controller
9- CH: Check Valve
10- PT: Pressure Transmitter

Oil Piping Data	
Working Pressure	2 – 25 Barg
Working Temperature	4 / 150` C
Design Pressure	31 Barg
Design Temperature	180` C

Atomising Media Piping Data	
Working Pressure	8 Barg
Working Temperature	4 0/ 180` C
Design Pressure	20 Barg
Design Temperature	65/ 210` C

Main Boiler Gas Conversion
Oil & Atomising Media Skid
Process & Instrumentation Diagram

Oil & Atomizing Media Skid
(Old Design)



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Design Temperature	180` C

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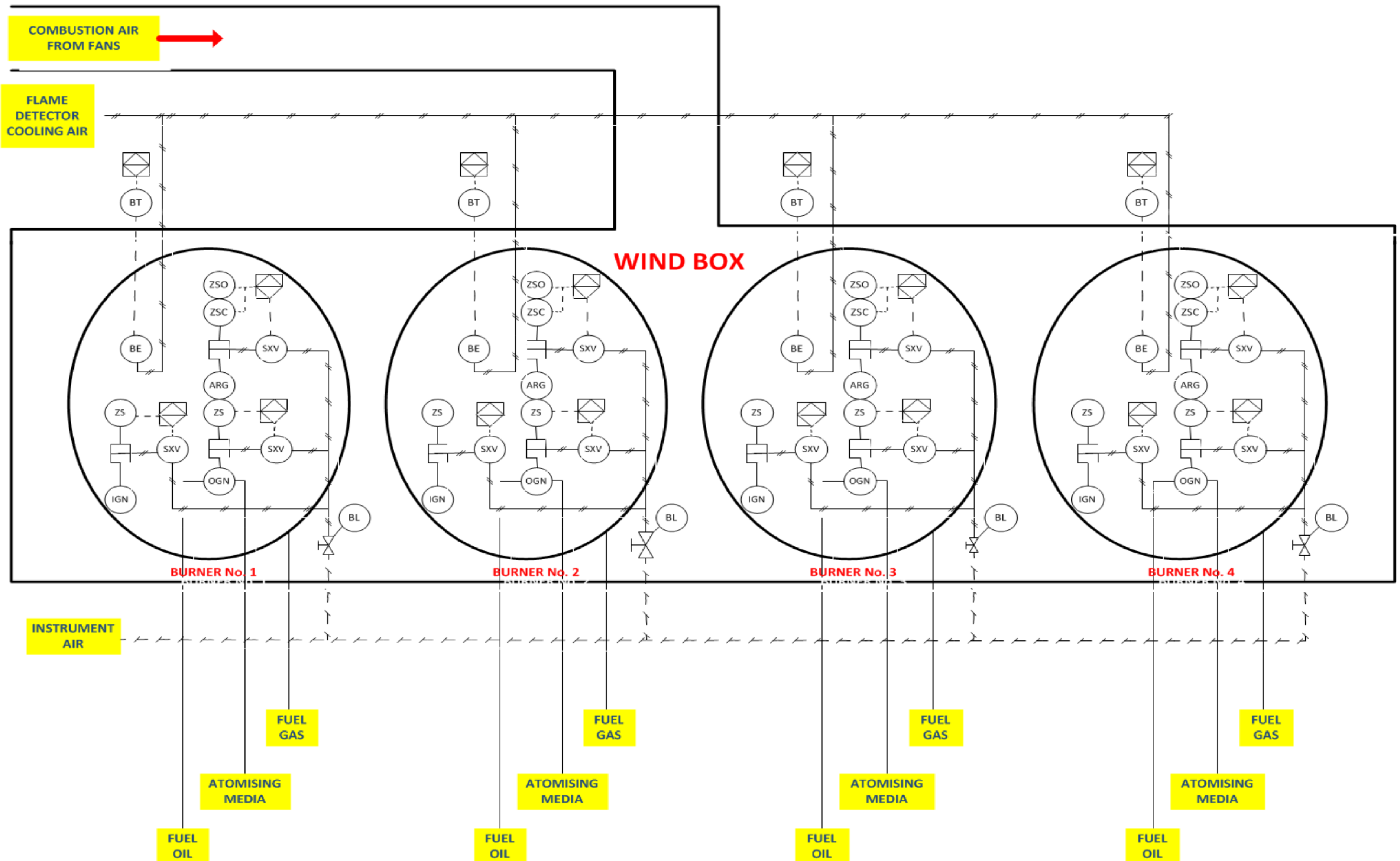
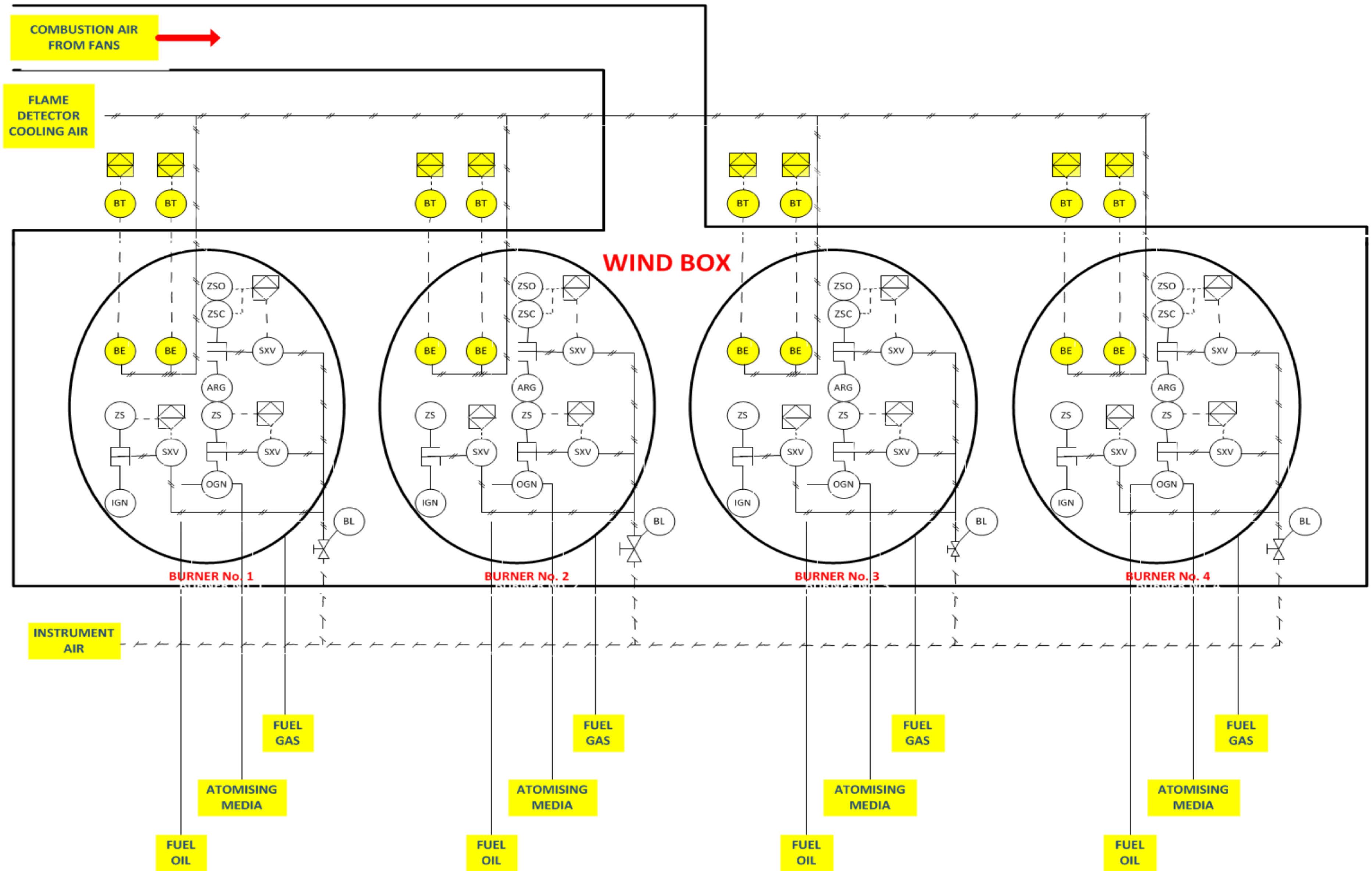
Working Pressure	8 Barg
Working Temperature	4 0/ 180` C
Design Pressure	20 Barg
Design Temperature	65/ 210` C

Main Boiler Gas Conversion
Oil & Atomising Media Skid
Process & Instrumentation Diagram

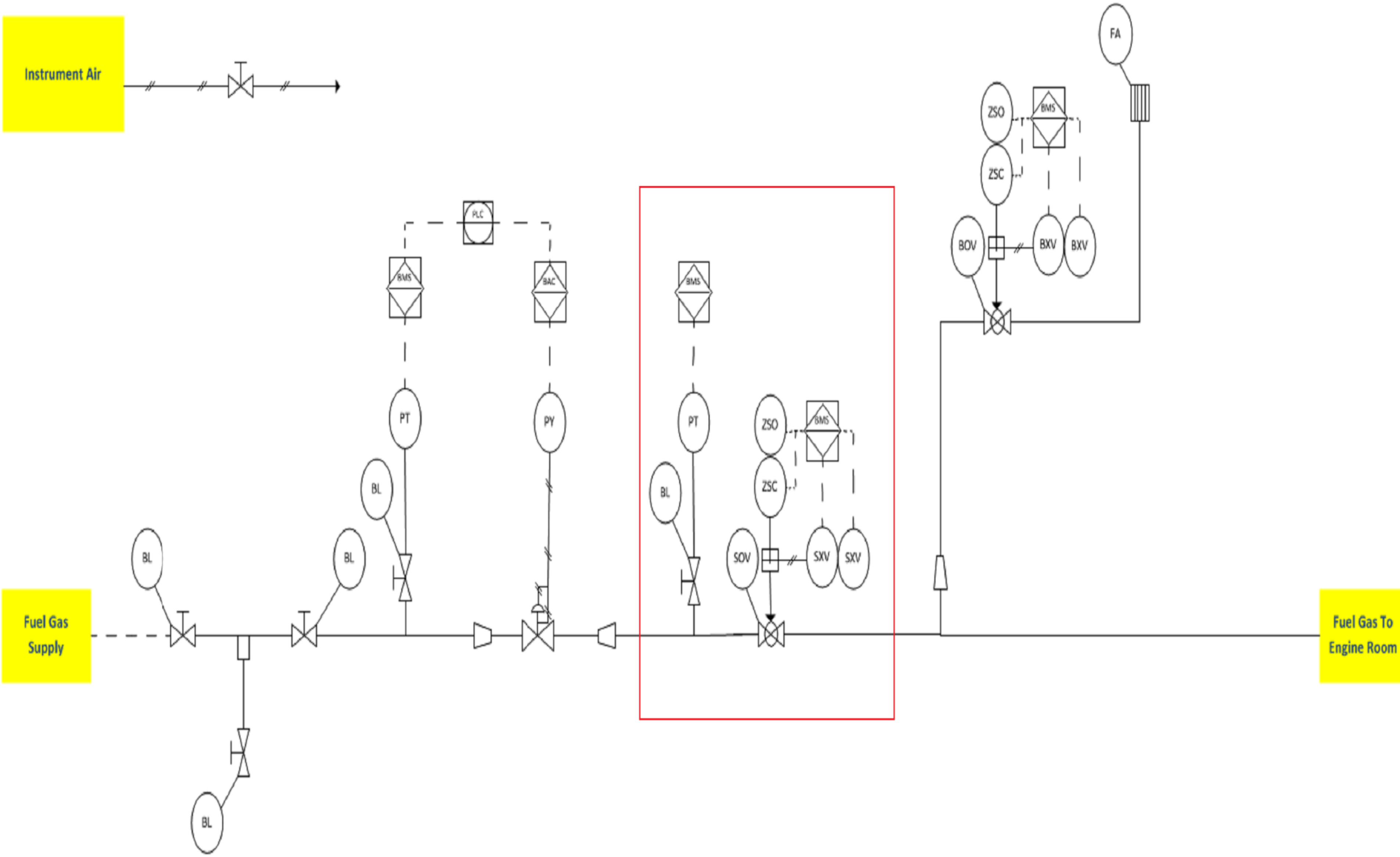
Oil & Atomizing Media Skid
(New Design)



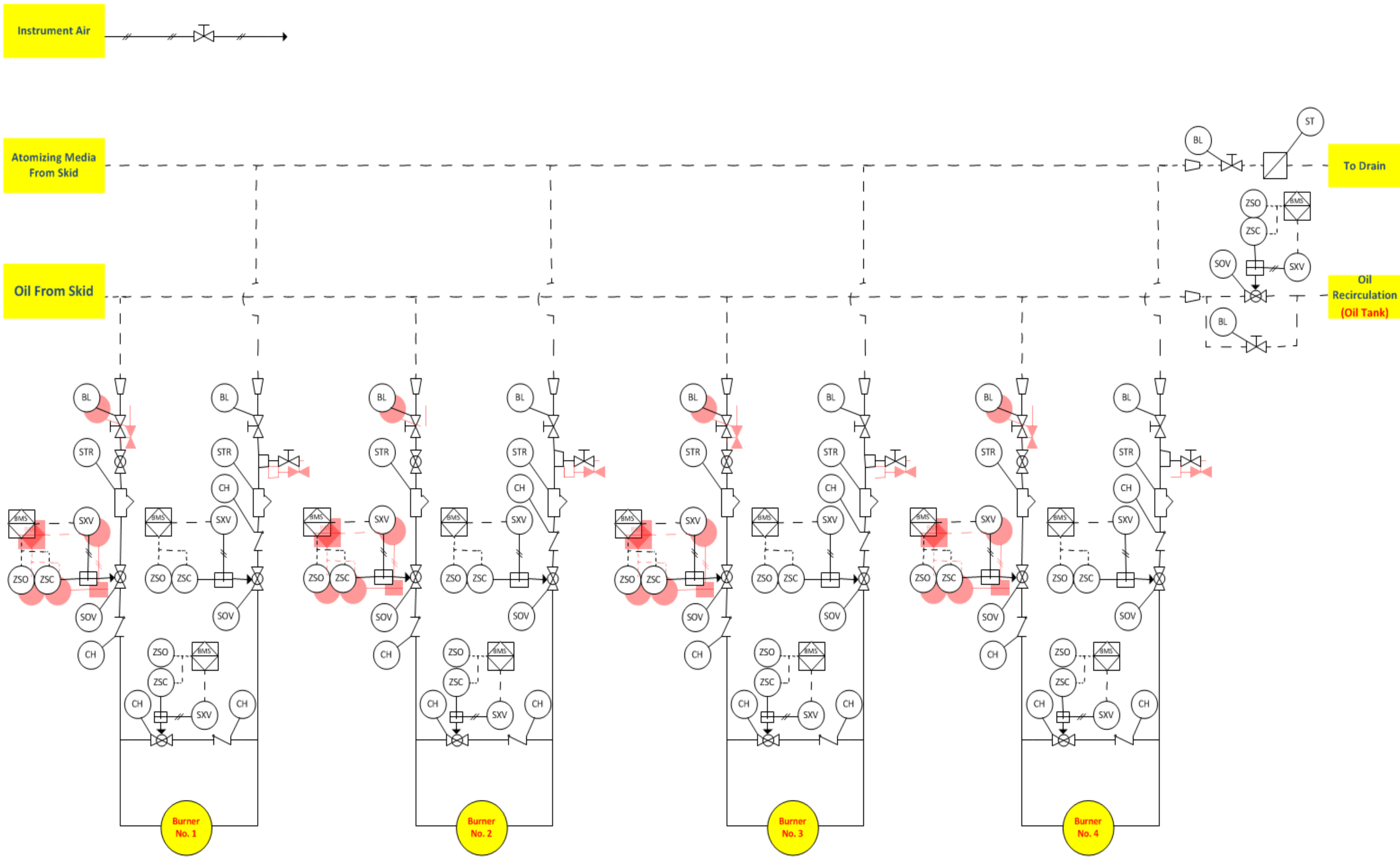
Burners (Old Design)



Burners New Design



New Deck Gas Supply Skid with additional Pressure Regulator



Main Boiler Burner Oil Piping Assemblies

Appendix-II

Glossary

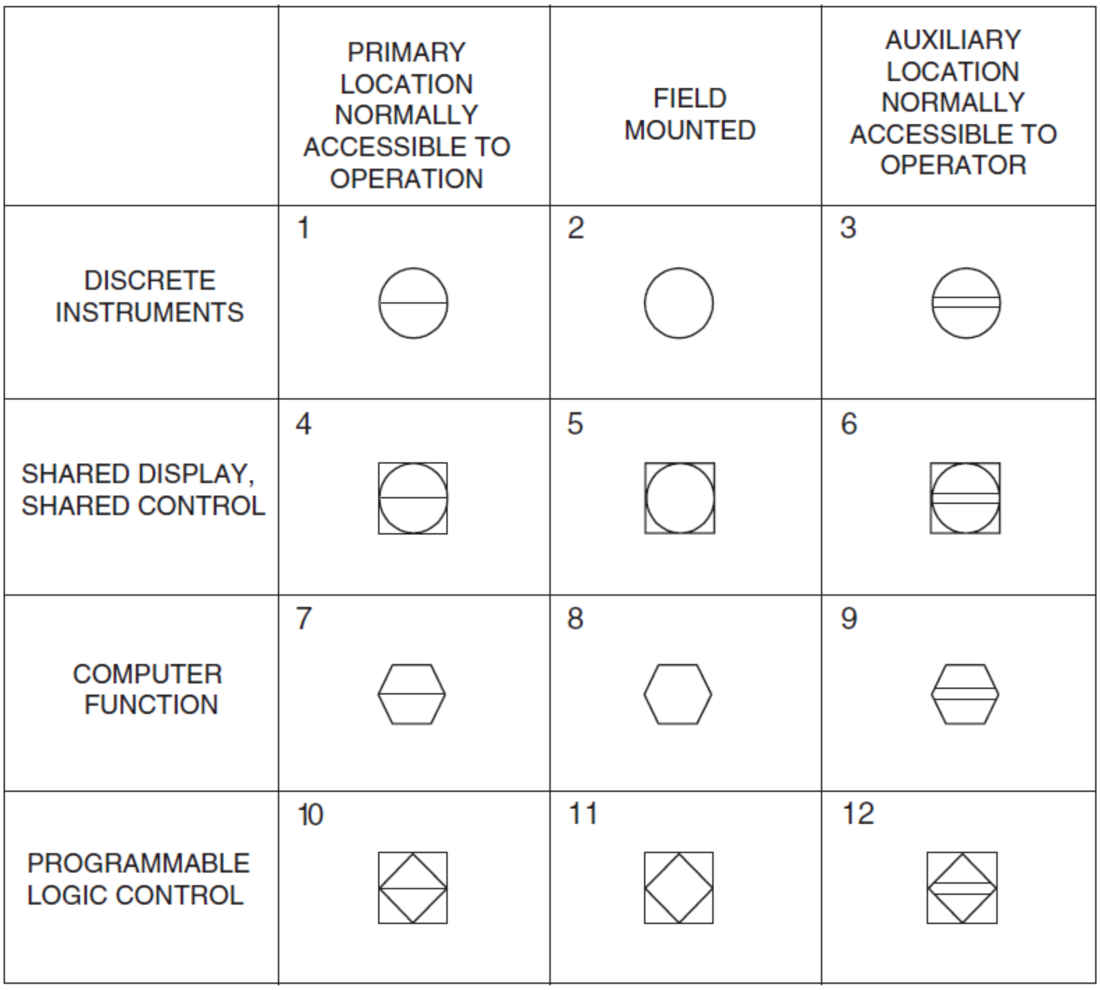
ITEM	Tag No.	DEVICE	SERVICE
1	BL-	Isolation Valve	Bnr. Regulated Gas Supply
2	PT-	Pressure Transmitter	Bnr. Regulated Gas Supply
3	PCV-	Pressure Control Valve	Bnr. Regulated Gas Supply
4	PY-	I/P Convertor on Pressure	Bnr. Regulated Gas Supply
5	SDV-	Shut Off Valve	Bnr. Regulated Gas Supply
6	ZSC-	Limit Switch - Closed	Bnr. Regulated Gas Supply
7	ZSO-	Limit Switch - Open	Bnr. Regulated Gas Supply
8	SXV-	Solenoid Valve	Bnr. Regulated Gas Supply
9	BDV-	Break Down Valve	Bnr. Regulated Gas Supply
10	BXV-	Solenoid Valve	Bnr. Regulated Gas Supply
11	FA-	Flame Arrester	Bnr. Regulated Gas Supply
12	FT-	Flow Transmitter	Gas Header
13	SOV/SDV-	Shut Off Valve	Gas Header
14	FCV-	Flow Control Valve	Gas Header
15	PG-	Pressure Gauge	Gas Header
16	BDV-	Break Down Valve	Gas Header
17	PSLL-	Pressure Switch Low Low	Instrument Air
18	FE-	Flow Sensor	Nitrogen Supply
19	CH-	Check Valve	Gas Header Nitrogen Purge
20	MO-	Mono Valve	Burner 1 Gas Supply
21	OR-	Orifice	Heavy Fuel Oil Recirculation
22	ST-	Condensate Trap	Atomising Steam Drain
23	PG-	Pressure Gauge	Atomising Media Supply
24	STR-	Strainer	Burner 1 Oil Supply
25	HV-	Isolation Valve	Instrument Air
26	ARG-	Air Register Actuator	Bnr 1 Air Register
27	IGN-	Igniter Actuator	Bnr 1 Igniter
28	ZS-	Limit Switch	Bnr 1 Igniter
29	OGN-	Oil Gun Actuator	Bnr 1 Oil Gun
30	ARG-	Air Register Actuator	Bnr 2 Air Register
31	GD-	Gas Detector	Ventilation Air Supply
32	PDSL-	Press. Diff. Switch Low	Ventilation Air Supply
33	KM-	Motor	Ventilation Air Supply
34	K-	Fan	Ventilation Air Supply
35	FA-	Flame Arrester	Ventilation Air Supply
36	FY-	I/P Convertor on Flow	Combustion Air Supply
37	PDT-	Differential Pressure Tx	Combustion Air Supply
38	AE-	BAC O2 Probe	Oxygen Triming
39	AT-	Oxygen Transmitter	Oxygen Triming
40	TT-	Temperature Transmitter	Air Heater Temperature
41	TY-	I/P Convertor on Temp	GAH Air By Pass Damper
42	LCV-	Level Control Valve	Feedwater Supply

43	TCV-	Temperature Control Valve	Water Drum
44	GL-	Isolation Globe Valve	Boiler Drum Level
45	LSHH-	Level Switch - High High	Boiler Drum Level

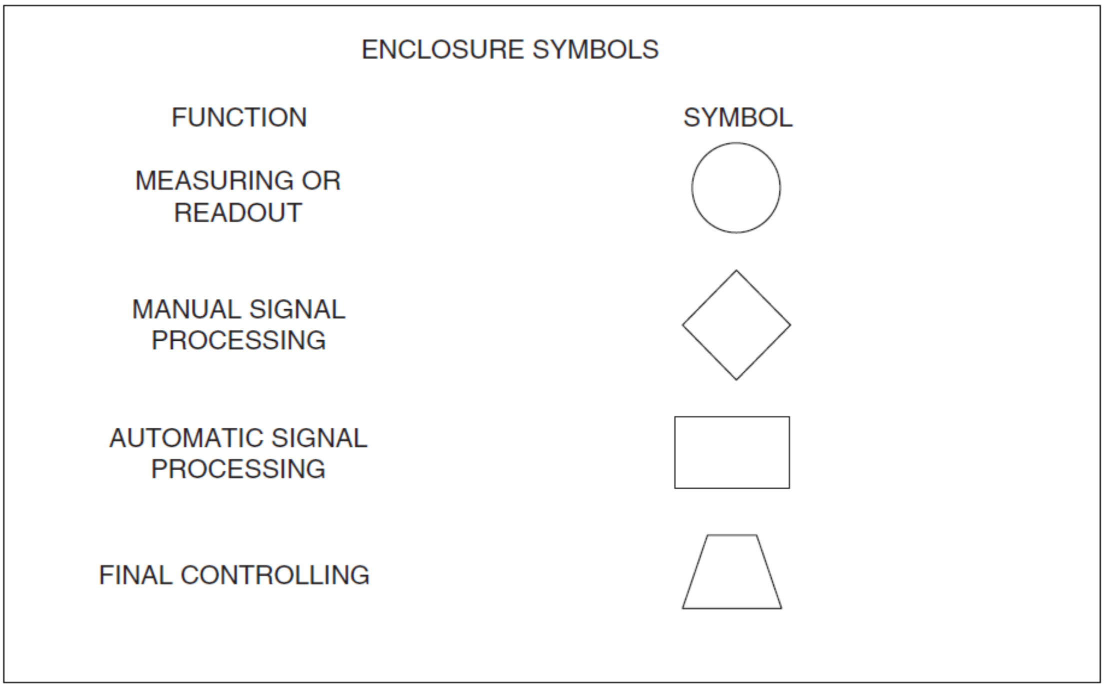
Appendix-III

ISA Control Diagramming System

ISA-77 General Instrument or Functional Symbols



SAMA Symbols (Scientific Apparatus Makers Association)



ISA Symbols

FUNCTION	SIGNAL PROCESSING SYMBOL	FUNCTION	SIGNAL PROCESSING SYMBOL
SUMMING	Σ or +	INTEGRATE OR TOTALIZE	Q
AVERAGING	Σ/n	HIGH SELECTING	$>$
DIFFERENCE	Δ or -	LOW SELECTING	$<$
PROPORTIONAL	K or P	HIGH LIMITING	$\ngtr$
INTEGRAL	$\int$ or I	LOW LIMITING	$\nless$
DERIVATIVE	d/dt or D	REVERSE PROPORTIONAL	-K or -P
MULTIPLYING	X	VELOCITY LIMITING	V $\ngtr$
DIVIDING	+	BIAS	$\pm$
ROOT EXTRACTION	$\sqrt{}$	TIME FUNCTION	f(t)
EXPONENTIAL	X^n	VARIABLE SIGNAL GENERATION	A
NON-LINEAR FUNCTION	f(x)	TRANSFER	T
TRI-STATE SIGNAL (RAISE, HOLD, LOWER)	$\updownarrow$	SIGNAL MONITOR	H/, H/L, /L

Appendix-IV

Glossary of Common Boiler Terms

Term	Definition
Alarm	An indicator or alert for operator about hazardous situation.
Steam Boiler	A steam generator used to produce steam by releasing excessive amount of heat which is transferred to water to convert it into steam.
Combustion	Mixing the atomizing media with the fuel inside the combustion chamber with the presence of flame.
Controller	Manual or automatic regulator used to operate the boiler with limitations for pressure, temperature and flow volume.
Boiler Efficiency	The ratio of heat released by combustion process to heat absorbed by water.
Final control element	A control device as a control valve that regulates fluid flow, pressure, temperature and boiler operation.
Interlock	A safety devices either hardware or software are used to sense and test operation limits and used to initiate alarm and stop the operation of the system during hazardous situation to avoid undesired conditions.
Fuel trip	Closing all fuel valves and preventing the fuel from flowing into the boiler during any hazardous situation.
Furnace	Combustion chamber that provides for combustion of fuel.
Furnace pressure	The pressure of gases in the furnace (see also draft
Piping and Instrument Diagrams (P&IDs)	Drawings show process control installation and the interconnections between controlling elements.
Master fuel trip (MFT)	Shutoff of all fuel valves.
Two-out-of-three logic circuit	A logic circuit that has three elements will achieve their objective only if two elements at least operate in a same mood.

Appendix-IV

Standards

NFPA code-85, 2011

Chapter 4 Fundamentals

4.1* Manufacture, Design, and Engineering.

4.1.1 The owner or the owner's representative shall, in cooperation with the manufacturer, ensure that the unit is not deficient in apparatus that is necessary for operation with respect to pressure parts, fuel-burning equipment, air and fuel metering, light-off, and maintenance of stable flame.

4.1.2 All fuel systems shall include provisions to prevent foreign substances from interfering with the fuel supply.

4.1.3* An evaluation shall be made to determine the optimum integration of manual and automatic safety features.

4.1.4 Although this code requires a minimum degree of automation, more complex plants, plants with increased automation, and plants designed for remote operation shall require additional provisions for the following:

(1) Information regarding significant operating events that allow the operator to make a rapid evaluation of the operating situation
(2) Continuous and usable displays of variables that allow the operator to avoid hazardous conditions
(3) In-service maintenance and checking of system functions without impairment of the reliability of the overall control system
(4) An environment conducive to timely and correct decisions and actions

4.1.5* The burner or fuel feed piping and equipment shall be designed and constructed to prevent the formation of hazardous concentrations of combustible gases that exist under normal operating conditions.

Single burner boiler:

5.3 Equipment Requirements.

5.3.1* Fuel Supply — Oil.

5.3.1.1 Fuel shall be stored, prepared, and delivered to the oil service connection under anticipated operating conditions in accordance with the applicable portions of NFPA 31, *Standard for the Installation of Oil-Burning Equipment.*

5.3.1.2 Operation of the burner shall not be attempted until a continuous fuel supply is ensured.

5.3.1.3 Fuel shall be delivered continuously to the combustion chamber in a finely atomized form that can be ignited readily and consumed.

5.3.1.4 All equipment that is associated with pumping, heating, and straining the fuel from storage to the service connection shall be designed, sized, and interconnected so as to provide a suitable fuel supply over a full range of conditions.

5.3.1.5 Relief valves shall be installed after the pump to prevent overpressure in the system.

5.3.1.6 Fuel being burned shall be delivered to the burner at the temperature and pressure specified by the burner manufacturer.

5.3.1.7 Where the fuel must be heated, the interlocks and instruments shall reflect the correct values of the variable being measured, particularly in dead-end lines, where heavy oil will tend to solidify.

5.3.1.8 Oil Supply.

5.3.1.8.1 The operation of a burner system that has the capability to burn heated and unheated oils shall include a procedure to ensure that the specified grade of oil, compatible with the selected mode of operation, is being supplied to the burner.

5.3.1.8.2 Precautions shall include the intended routing of recirculated oil.

5.3.1.9 Two safety shutoff valves in series, each with a proof of closure switch, shall be provided in the oil line to the main burner.

5.3.1.10 Where pressure can develop in excess of the valve or piping rated pressure(s), the piping design shall include a means to prevent or relieve excess pressure between the valves.

5.3.1.11 Oil piping materials and system design shall be in accordance with NFPA 31, *Standard for the Installation of Oil-Burning Equipment* (for oil piping inside industrial or institutional buildings), ASME B31.1, *Power Piping* (for oil piping in power applications), or ASME B31.3, *Process Piping* (for oil piping in process applications).

5.3.2* Fuel Supply — Gas.

5.3.2.1 The gas supply at the gas service connection shall be controlled at the pressure for which the fuel-burning system had been designed.

5.3.2.2 Gas piping shall be sized to maintain the desired constant pressure for maximum burner flow.

5.3.2.3* Two safety shutoff valves in series, each with a proof of closure switch, shall be provided in the fuel gas line to the main burner, and an automatic vent valve shall be provided between the two valves. When a listed automatic valve-proving system is used with two safety shutoff valves in series, each with a proof of closure switch, the automatic vent valve shall be permitted to be omitted.

5.3.2.3.1* Valve proving shall be performed either after every burner shutdown or prior to every burner light-off.

5.3.2.4 Foreign matter such as welding beads, chips, scale, dust, and debris shall be removed from the gas piping.

5.3.2.5 A drip leg shall be provided in the gas piping. *(See A.5.3.2.3 and A.5.3.4.1.)*

5.3.2.6 Gas piping material and system design shall be in accordance with NFPA 54, *National Fuel Gas Code* (for gas piping inside industrial and institutional buildings), ASME B31.1, *Power Piping* (for gas piping in power applications), or ASME B31.3, *Process Piping* (for gas piping in process applications).

5.3.2.7 Valve Leakage Test.

5.3.2.7.1 Permanent means shall be provided for making valve leakage tests of the main burner gas safety shutoff valves.

5.3.2.7.2 Valve leakage tests of the main safety shutoff valves

6.3 Mechanical Equipment Requirements.

6.3.1 General requirements for mechanical equipment shall be in accordance with Sections 4.6 through 4.16.

6.3.2 Forced draft (FD) and induced draft (ID) fans shall include all fans whose purpose is to supply air for combustion or remove products of combustion, including associated booster fans, and exclude fans in the pulverized coal system.

6.3.3 Fuel Gas and Fuel Oil Safety Shutoff Valves.

6.3.3.1 A header safety shutoff valve and individual burner safety shutoff valves shall be provided.

6.3.3.2 Proof of closure shall be provided for all header and burner safety shutoff valves.

6.3.3.3 Multiple burners supplied from a common set of burner safety shutoff valves shall be treated as a single (individual) burner. *(See 6.6.7.1.3 and 6.7.7.1.3 for two-burner units.)*

6.3.3.4 Where fuel gas or fuel oil igniters are provided, a common igniter fuel header safety shutoff valve and individual igniter safety shutoff valves shall also be provided. The igniter header safety shutoff valve shall be dedicated to the igniter subsystem.

6.3.3.5 Multiple igniters supplied from a common set of igniter safety shutoff valves shall be treated as a single (individual) igniter.

6.3.3.6 Proof of closure in accordance with 6.4.2.3.4.5 shall be provided for all individual igniter safety shutoff valves.

6.3.3.7 Burner and igniter safety shutoff valves shall be located as close as practicable to the igniters or burners to minimize the volume of fuel downstream of the valve.

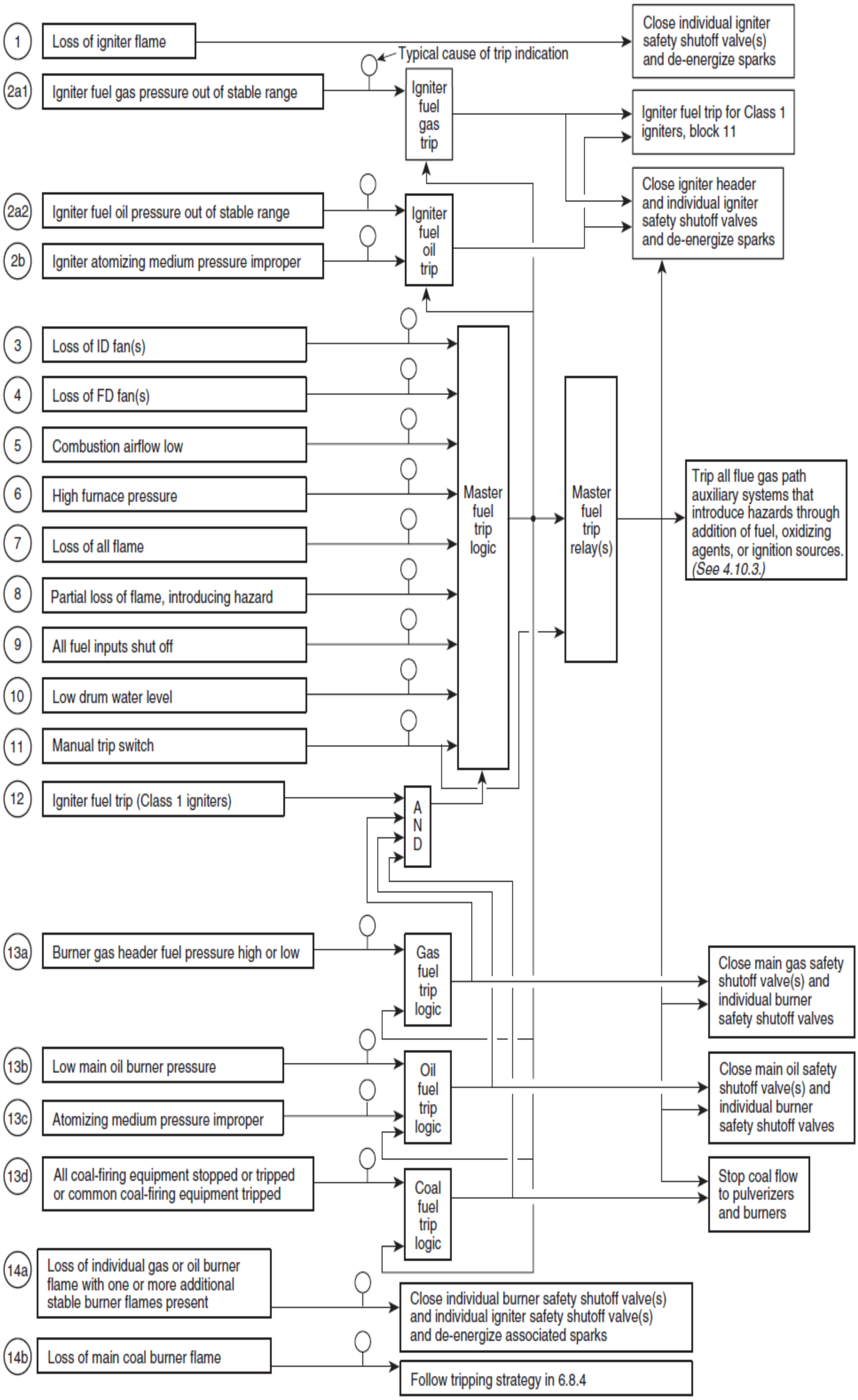


FIGURE 6.4.2.3.1 Interlock System for Multiple Burner Boiler.

6.5 Furnace Implosion Protection.

6.5.1* General. The structural design requirements of Section 4.6 shall apply to both pressure fired and balanced-draft units.

6.5.1.1 Transient Design Pressure.

6.5.1.1.1 The furnace structural design shall be such that the furnace is capable of withstanding a transient design pressure without permanent deformation due to yield or buckling of any support member.

6.5.1.1.2 This transient design pressure need not be considered as acting simultaneously with other transient loads such as wind load or seismic load.

6.5.1.2 Pressure Fired Units. Implosion protection requirements shall not apply to units without a fan located in the flue gas path downstream of the boiler enclosure.

6.5.1.3* Balanced Draft Units. All boilers with a fan located in the flue gas path downstream of the boiler enclosure shall be designed in accordance with either 6.5.1.3.1 or 6.5.1.3.2.

6.5.1.3.1 The furnace and flue gas removal system shall be designed so that the maximum head capability of the ID fan system with ambient air does not exceed the continuous design pressure of the furnace, ducts, and associated equipment.

6.5.1.3.2 Where a furnace pressure control system in accordance with 6.5.2 is provided, the furnace shall be designed for the transient design pressures in 6.5.1.3.2.1 and 6.5.1.3.2.2.

6.5.1.3.2.1* Positive Transient Design Pressure.

(A) If the test block capability of the FD fan at ambient temperature is equal to or more positive than +8.7 kPa (+35 in. of water), the positive transient design pressure shall be at least, but shall not be required to exceed, +8.7 kPa (+35 in. of water).

(B) If the test block capability of the FD fan at ambient temperature is less positive than +8.7 kPa (+35 in. of water), the positive transient design pressure shall be at least, but shall not be required to exceed, the test block capability of the FD fan.

This legend applies to Figure 7.7.1.3(a) through Figure 7.7.1.3(e).

- A Burner header shutoff valve
- B Individual burner safety shutoff valve
- C_1 Burner header atmospheric vent valve
- C_2 Individual burner atmospheric vent valve
- C_4 Igniter header atmospheric vent valve
- C_5 Individual igniter atmospheric vent valve
- D Burner header fuel control valve
- D_1 Burner header fuel bypass control valve
- E Igniter header safety shutoff valve
- F Igniter fuel control valve
- G Individual igniter safety shutoff valve
- H Recirculating valve
- I Charging valve (optional — required to be self-closing)
- J Constant fuel pressure regulator
- K Pressure relief valve
- L Leakage test connection
- M Flowmeter
- N Low atomizing media pressure switch
- O Strainer or cleaner
- P Restricting orifice
- Q Low fuel pressure switch
- Q_1 Low fuel supply pressure switch [pressure switch low (PSL)]
- R High fuel pressure switch
- R_1 High fuel pressure switch (alternate location)
- R_2 High fuel supply pressure switch [pressure switch high (PSH)]
- S Pressure gauge
- T Manual shutoff valve
- U Temperature indicator
- V Burner header atmospheric vent valve, manual
- Y Check valve

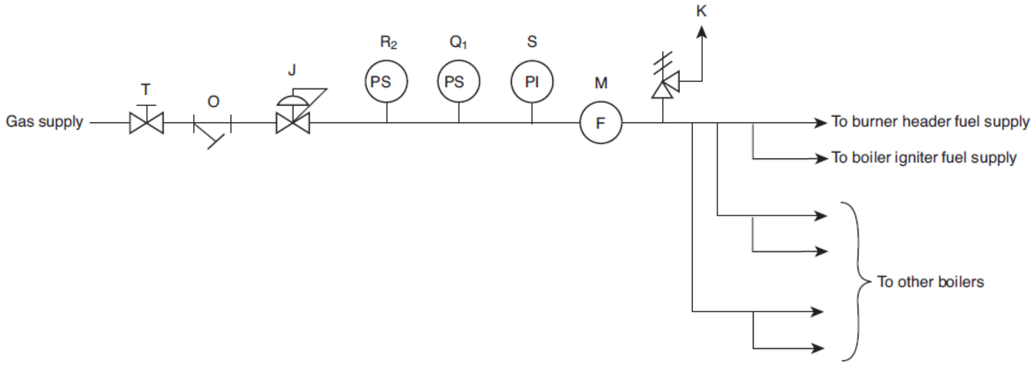


FIGURE 7.7.1.3(a) Fuel Gas Supply to Power House.

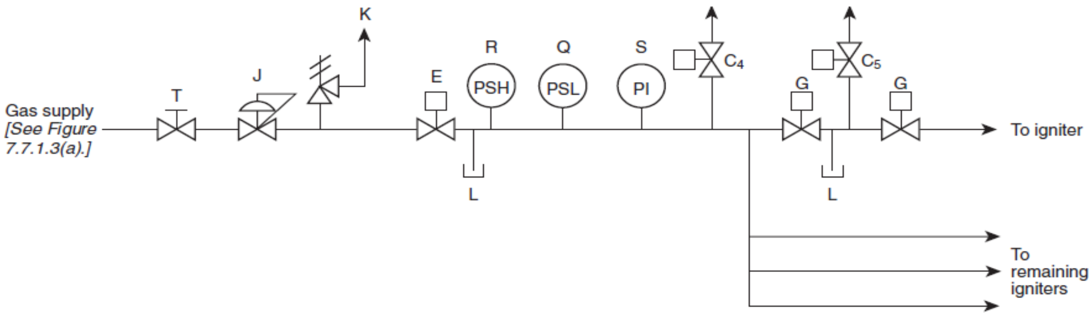


FIGURE 7.7.1.3(b) Fuel Gas Ignition System — Multiple Igniters Supplied from a Common Header (Automatic).

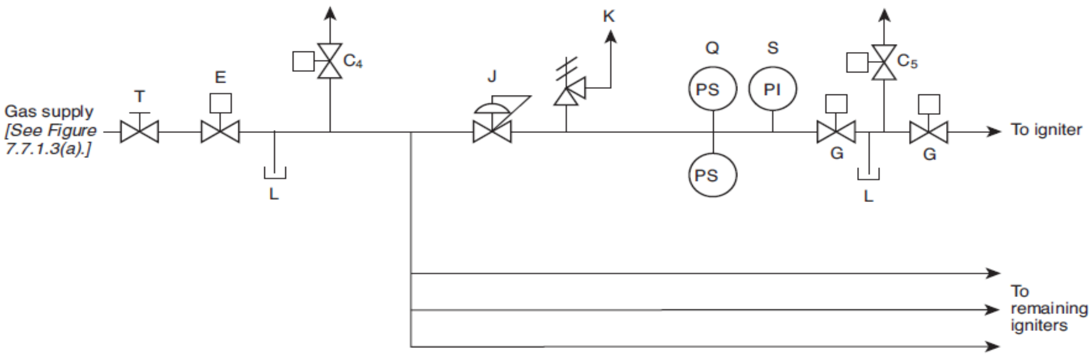
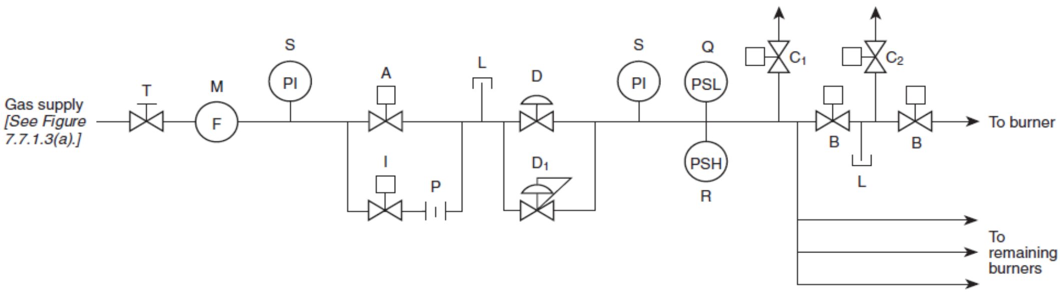


FIGURE 7.7.1.3(c) Fuel Gas Ignition System — Individually Controlled Igniters (Automatic).



PG-69 CERTIFICATION OF CAPACITY OF PRESSURE RELIEF VALVES

PG-69.1 Before the Code symbol is applied to any pressure relief valve or power-actuated pressure relieving valve, the valve manufacturer shall have the relieving capacity of his pressure relief valves certified in accordance with the provisions of this paragraph.

PG-69.1.1 Capacity certification tests shall be conducted using dry saturated steam. The limits for test purposes shall be 98% minimum quality and 20°F (10°C) maximum superheat. Correction from within these limits may be made to the dry saturated condition.

PG-69.1.2 Tests shall be conducted at a place that meets the requirements of A-312.

PG-69.1.3 Capacity test data reports for each pressure relief valve design and size, signed by the manufacturer and Authorized Observer witnessing the tests, together with drawings showing the valve construction, shall be submitted to the ASME designee for review and acceptance.[24]

PG-69.1.4 Capacity certification tests shall be conducted at a pressure that does not exceed the set pressure by 3% or 2 psi (15 kPa), whichever is greater. Pressure relief valves shall be adjusted so that the blowdown does not exceed 4% of the set pressure. For pressure relief valves set at or below 100 psi (700 kPa), the blowdown shall be adjusted so as not to exceed 4 psi (30 kPa). Pressure relief valves used on forced-flow steam generators with no fixed steam and waterline, and pressure relief valves used on high-temperature water boilers shall be adjusted so that the blowdown does not exceed 10% of the set pressure. The reseating pressure shall be noted and recorded.

PG-69.1.5 Capacity certification of pilot operated pressure relief valves may be based on tests without the pilot valves installed, provided prior to capacity tests it has been demonstrated by test to the satisfaction of the Authorized Observer that the pilot valve will cause the main valve to open fully at a pressure which does not exceed the set pressure by more than 3% or 2 psi (15 kPa), whichever is greater, and that the pilot valve in combination with the main valve will meet all of the requirements of this Section.

PG-69.1.6 Pressure relief valves for economizer service shall also be capacity certified using water at a temperature between 40°F and 125°F (4°C and 50°C). The pressure relief valves shall be tested without change to the adjustments established in PG-69.1.1 to PG-69.1.4.

PG-69.2 Relieving capacities shall be determined using one of the following methods.

PG-69.2.1 Three Valve Method. A capacity certification test is required on a set of three pressure relief valves for each combination of size, design, and pressure setting. The capacity of each valve of the set shall fall within a range of ±5% of the average capacity. If one of the three pressure relief valves tested falls outside this range, it shall be replaced by two valves, and a new average shall be calculated based on all four valves, excluding the replaced valve. Failure of any of the four capacities to fall within a range of ±5% of the new average shall be cause to refuse certification of that particular valve design.

The rated relieving capacity for each combination of design, size, and test pressure shall be 90% of the average capacity.

PG-69.2.2 Slope Method. If a Manufacturer wishes to apply the Code Symbol to a design of pressure relief valves, four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures that cover the approximate range of pressures for which the valve will be used or covering the range available at the certified test facility that shall conduct the tests. The capacities based on these four tests shall be as follows:

(a) The slope W/P of the actual measured capacity versus the flow pressure for each test point shall be calculated and averaged

For steam

$$\text{slope} = \frac{W}{P} = \frac{\text{measured capacity}}{\text{absolute flow rating pressure}}$$

For water

$$\text{slope} = \frac{W}{P} = \frac{\text{measured capacity}}{\sqrt{(\text{flow rating pressure}) - (\text{discharge pressure})}}$$

All values derived from the testing must fall within ±5% of the average value

$$\text{minimum slope} = 0.95 \times \text{average slope}$$

$$\text{maximum slope} = 1.05 \times \text{average slope}$$

If the values derived from the testing do not fall between the minimum and maximum slope values, the Authorized Observer shall require that additional valves be tested at the rate of two for each valve beyond the maximum and minimum values with a limit of four additional valves.

For steam applications the relieving capacity to be stamped on the valve shall not exceed 90% of the average slope times the absolute accumulation pressure

$$\text{rated slope} = 0.90 \times \text{average slope}$$

For water applications the relieving capacity shall not exceed 90% of the average slope multiplied by the square root of the difference between the flow rating pressure and the valve discharge pressure.

$$\text{rated slope} = 0.9 \times \text{average slope} \times \sqrt{\text{flow rating pressure} - \text{discharge pressure}}$$

(U.S. Customary Units)

stamped capacity ≤ rated slope (1.03 × set pressure + 14.7) or (set pressure + 2 psi + 14.7), whichever is greater

(SI Units)

stamped capacity ≤ rated slope (1.03 × set pressure + 0.101) or (set pressure + 0.015 MPa + 0.101), whichever is greater

Appendix-V

Awards

Awards

The Project was awarded a silver medal in Science and Engineering Design Exhibition UTP (SEDEX - 31) in August 2013.

Figure 16 SEDEX Certificate