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Risk Engineering Bulletin

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In Focus

Boiler Explosion

Did you know?
Interesting facts on Boilers

Disasters
Boilers incidents involving Explosion and Fire

Hazards associated with Boilers
Major risk drivers leading to Boiler Failure

Loss Prevention
Procedures for controlling hazards in Boiler

Guidelines
Codes & Standards

Engage
Solve Questions and Win Prizes

Preface

18th century saw the invention of steam boilers. The steam power industry owes its existence to the birth of convection boilers, which were invented by George Babcock and Stephen Wilcox. During the period between 1867 and 2020, there have been several advancements in Boiler design, in terms of efficiency, precision in operation control, emission levels and safety.

Boilers are an integral and key part of various industries. Some of the major industrial applications of boilers are Power Generation, Petroleum Refineries, Chemical Manufacturing, Steel Plants, Pulp and Paper etc. Boilers are designed and built to operate under high temperature and pressure conditions. Boiler explosion can be devastating. A boiler explosion can lead to multiple fatalities and in some cases, can even lead to evacuation of an area.

An analysis of past losses reveals that, poor safety systems, human errors and process related failures have been the major contributors to catastrophic boiler explosions. This document will provide you with a brief overview on boiler explosion, a look at some of the recent boiler explosion incidents, hazards associated with boilers, best practices involved in operation and maintenance of boilers and the loss control measures which can prevent boiler explosions.

Did You Know?

- Boilers were built as early as the 1st century AD by Hero of Alexandria but were used only as toys. The first boiler with a safety valve was designed by Denis Papin of France in 1679.
- Late 1700s saw the development of the kettle-type boiler; a simple design that featured water placed above a fire box that was boiled into steam. In 1867, invention of the convection boiler, which ushered in the steam-generating industry.
- Fossil-fuel based boilers are major emitters of carbon dioxide in the world.
- In a Pulverised fuel Boiler, the size of the coal particles is of size 75 microns and combustions takes place at temperature between 1300-1500 deg. Celsius.
- Water (at100°C and at atmospheric pressure) when converted to steam, expands ~1600 times in volume. (i.e.) 1 m^3 of water converts into 1600 m^3 of steam.

Disasters

Boiler explosion in a newly commissioned thermal power plant

On November 01, 2017 a boiler explosion happened in newly commissioned 500 MW unit of a coal fired thermal power plant located in Northern part of India. Reportedly, the accident resulted in unfortunate death of 45 people and severe burn injuries to many. This happened even when the organisation had a long history in safety and handling of similar projects. The cause of this accident was believed to be dislodging of clinkers which were formed covering the water wall surface in the boiler and subsequent rupture of boiler tubes due to pressurization of boiler vessel.

After deliberations, Unit load was reduced but no shut down was taken. The ash build-up inside the boiler was planned to be cleared manually by using workers to poke the clinkers via manhole and direct it towards the bottom ash hoppers. In addition, High Pressure fire hydrant jets were also being sprayed onto the slag in the furnace from the manhole. While dislodging the clinker at the bottom hopper, a huge hot clinker from higher elevation fell into the hopper (containing water) and quickly vaporised the water.

This resulted simultaneous pressurizing of the vessel and the furnace leading to an explosion; resulting in puncture of water wall tubes at one of the corners. Hot slag with steam-water mixture slashed around affected corner up to the bottom elevations below 08m, injuring workers present in around the vicinity of boiler. At the same time, partially burnt coal was carried into the second pass of the tubes due to pressurisation, resulting in blowing-off of the economizer's hopper.

Boiler Explosion at Chemical Complex

In the early hours of December 09, 2000 at a Chemical Complex located in South Asia, a group of three technicians of the operations team were trying to restart the boiler as instructed by the Senior Officials.

The boiler exploded violently wherein the explosion had demolished the boiler and its associated equipment by causing severe burn injuries to the technicians.

The investigations found that the boiler was in commissioning stage and had the provision of using 08 different types of fuels through various nozzles provided. The Operations team made several attempts in restarting the boiler which were unsuccessful.

At 0220 hours, technicians reportedly used the diesel burner, which resulted in Master Fuel Trip and Shut-Off the fuel systems completely. Hence, LPG burner was chosen to restart which was unsuccessful during the initial attempts. A bypass procedure was used by the commissioning team in their attempt to restart the boiler which resulted in explosion.

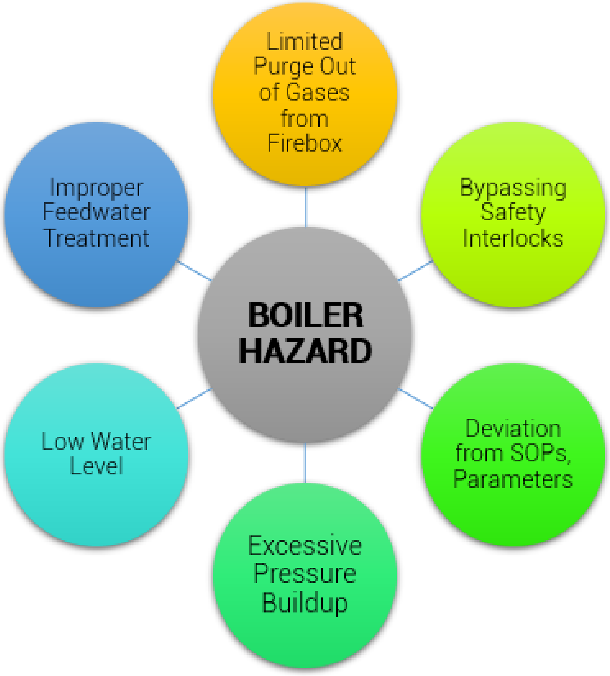
It was noted that the two bypass valves were already 50% open, resulting in accumulation of gas in the furnace prior to ignition, this led to explosion when attempted to restart the boiler. There were no documents available supporting Pre-Start-up Safety Review (PSSR) carried out before start-up and Management of Change (MOC) approval for using the bypass procedure.

Hazards Associated with Boilers

Boiler is a heating vessel which transfers heat energy associated with fuel to a working fluid. Water is heated in the tubes of the boiler to generate steam i.e. by combustion of fuel in the furnace at high temperature resulting in transfer of heat flux into the water wall tubes. The steam produced is of higher pressure and temperature and thus boiler operation poses higher degree of fire and explosion hazards which are catastrophic in nature.

Based on the historical data and root causes identified in the past incidents, boiler experts opine that boiler explosions can always be prevented. The major hazards associated with boiler are shown in the image below. The major risk drivers that lead to failure at boilers are broadly classified as below.

- Steam Explosions
- Furnace Explosions
- Tube Failures
- Improper Feedwater Treatment
- Frequent Thermal Cycling
- Poor Maintenance Practices



Steam Explosions

Overheating of Tubes

Contaminants present in the makeup water, corrosion products formed with steam cycle and contaminants resulting from condenser tube leakage are the principal contributing factors to the formation of heat deterrent scale or deposits in boiler tubes. These deposits are found in tube coils which are horizontally placed at different zones of the boiler i.e. where sludge or scale particles may settle on the lower part of the tube.

This may form a porous coating, restricting the access of water to the tube wall, eventually allowing the tube wall temperature to increase to a level permitting corrosion attack due to steam pockets. As the temperature of the tube wall increases, it becomes weak, and the internal pressure causes a bulge to develop. If the bulge extends far enough, cracking will occur resulting in steam explosion.

Low Water Level

Absence of water (which acts as cooling media) in the evaporator surface results in abrupt rise in tube metal temperature reducing the strength of the tube and thus causing rupture. Prolonged operation at low water levels could cause catastrophic damage to the steam and water circuit.

The principal factors contributing to low water level in boilers are defective low water level cut-off / low water cut-off protection being bypassed, Improper blowdown procedure, tampering with low water control, feedwater pump failure, control valve failure, loss of water to the deaerator or make-up water system, drum level controller failure, Drum level controller inadvertently left in the manual position, loss of plant air pressure to control the valve actuator, safety valve lifting, large and sudden change in steam load.

Failure to Operate Safety Valve

This is either due to valve being damaged or valve being corroded, or valve left in gagged condition after hydro test. Sudden over-pressurisation at boiler due to load throw-off scenario can result in pressurization of boiler. Operation failure of the safety valve can lead to rupture of tubes.

Furnace Explosions

The major fire hazard associated with a boiler is a furnace explosion which are the result of the ignition of combustible mixtures of fuel and air that have accumulated in the confined spaces of the boiler. Generally, such accumulations are the result of malfunction in combustion control and safeguard system or operator error associated with an inadequate or improper purge or incorrect operation of the burner equipment.

Insufficient Combustion Air

Inadequate supply of combustion air inside furnace can result in loss of flame in a portion of the boiler and improper combustion causes deposition of unburnt fuel on surfaces in different zones of the boiler. This leads to flame failure and tripping of boiler. But if combustion controls are tampered, it can result in furnace explosion.

Inadequate Ignition

Low oil pressure at pilot or gun may not ignite the main flame but continues to accumulate fuel inside the furnace. This delayed ignition during start-up can lead to furnace explosion in the furnace. In multi-burner units, the loss of flame at one or more burners may allow an explosive mixture to accumulate, only to be ignited by other burners, either while operating normally or while being lighted.

Fuel Safety Shutoff Valves

Leaks in fuel safety shut-off valve can cause fuel to flow and deposit inside the idle furnace. During re-start operation when burners are ignited can lead to uncontrollable ignition of fuel resulting in furnace explosion.

Faulty Draft Controls

Total loss of flame or substantial changes in airflow may cause negative pressure excursions known as furnace implosions which can be extremely damaging.

Failing to Purge during Restart

An example for operator can be the failure to purge the furnace of combustible mixtures between repeatedly unsuccessful attempts to light off the burner. Total loss of flame or substantial changes in airflow may cause negative pressure excursions known as furnace implosions which can be extremely damaging.

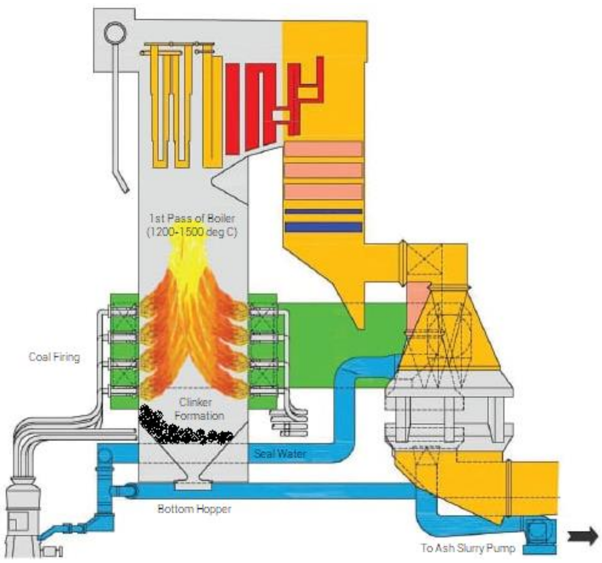
Carryover of unburnt fuel particles from the boiler combustion chamber may result from poor or inadequate fuel/air ratio control, malfunction of a inlet fuel valve, or the loss of a forced-draft fan. This carryover presents a hazard to equipment, such as air preheaters, electrostatic precipitators, and baghouse filters, in the downstream flue gas train. Flue gas scrubbers, which are also located in the flue gas train, generally operate wet and are not normally affected by carryover. However, they usually have combustible linings which are a hazard whenever the scrubber is not in operation, or if the water spray system fails during operation.

Furnace Explosion while dislodging Clinker

Two coal fire thermal power stations of India have witnessed catastrophic boiler explosions in consecutive years of 2016 and 2017 that have caused severe damage to life and property. Investigations of incidents revealed that both the incidents could have been avoided.

Clinker formation is a complex series of mineralogical transformations and phase changes that occur as coal burns. They are formed in the high temperature zones of the boiler which is mainly the furnace with operating temperature between 1200-1500 deg. Celsius, when non-combustible elements contained in coal such as iron, calcium, silicon, aluminium and sodium interact with sulphur and carbon at high temperatures.

These elements melt together with clays and alkalis to form a glassy slag that eventually hardens into clinkers. Small clinkers can fuse together to form large ones that can physically damage boilers. The illustration shown on right represents furnace with clinker formation around the bottom most panel of the furnace water wall tubes.



In both the explosion events, manual poking of clinkers along with spray of fire hydrant jets on the clinker surface was carried out from the manhole at the furnace bottom. This eventually led to dislodging of clinker at higher elevation into the bottom ash hopper resulting in sudden pressurisation of boiler and explosion.

Tube Failures

Tube failure is one of the most prominent causes that leads to forced outages in boiler, A tube fails when the metal weakens to such an extent that it cannot withstand internal pressure or other stress to which it may be subjected. The nature of the fracture, the size and shape of the opening, and the appearance of the edges, as well as the condition of the internal surface, usually indicate the cause of failure and it occurs about the same frequency in both the radiant and convection zones of the heat transfer.

Improper Feedwater Treatment

With improper feedwater treatment, problems can range from the rupture of a single tube to the destruction of an entire boiler. The problems could be the result of scaling or corrosion of pressure parts, both of which can be controlled through proper water conditioning.

Scaling can also affect thermal efficiency of the boiler. Both makeup water and condensate from process steam or turbines should be treated. Conditioning can also alleviate the problem of solids carryover in the steam. Solids can be removed from boiler water if they settle out through a blowdown procedure. The blowdown process is not used with “once through” boilers. Solids are, instead, removed through water conditioning.

Frequent Thermal Cycling

In general, coal fired power plants are designed to serve as base load installations, but in the recent times we have seen increased penetration of renewables into the grid. This has led to frequent cycling of thermal plants resulting in unforeseen stresses being introduced to metallurgy of major components of boiler pressure parts and steam turbine.

Load cycling may include low-load conditions, hot start-up, warm start-up, and/or cold start-up. During cyclic operations, tube-to-header welds develop cracking due to a combination of fatigue stresses and hoop stresses. Fatigue stresses can result from relative movement between the components, specifically during warm-up or cool-down, or when load changes occur, due to transient stresses.

During cycling of units, low-temperature regions of boiler subjected to thermal fatigue cracking in economizer inlet headers or tubes, lower furnace wall tubes or headers, and steam drum internals. This fatigue cracking primarily occurs from ingress of relatively colder water into hot boiler components or vice versa.

Rapidly ramping up, load on a boiler may lead to short-term overheating failures, due to presence of condensate in system, low points can cause increased metal temperatures. The tensile strength of steel decreases significantly once it crosses design temperatures. Also, rapid startups and shutdowns, as well as load changes on the boiler, can cause exfoliation of the inner diameter oxide scale.

Poor Maintenance Practices

Original Equipment Manufacturer (OEM) of the Boiler specifies rolling calendar for annual overhauls along with the set of activities to be carried out after completion of specified Equivalent Operating Hours (EOH). In addition, there are regulations at state level which are to be adhered in the process of obtaining or renewing the boiler licence. The root cause identified for most of the catastrophic failures have pointed out a human element i.e., poor maintenance practices or failure to adhere the set maintenance rolling plan and allowing unit to operate.

Hence as scheduled maintenance activities if neglected, the problems and issues will compound and may ultimately lead to a catastrophic failure of the boiler. Neglecting boiler maintenance will not only put operational personnel at risk, but result in premature failure of components and equipment, and ultimately cost a company through inefficiency, downtime, repairs, and replacements.

Loss Prevention

Boilers are one of the critical and high hazard equipment being used across many industries. However, with diligent inspection and maintenance by trained professionals, boilers can be operated safely and with high efficiency. The following are best practices followed in terms of inspection to be carried out during outage or overhaul to minimise the hazards associated with boiler.

- Ensure Static Interlocks and protections of all critical systems and equipment are tested at least once a year or during overhauls i.e. by incorporating periodic checks by simulating or relevant procedures. (At the end of the outage simulating scenarios / faults & checking MFT and checking healthy working of protection).
- Conduct conditioning monitoring of the boiler by using Non-Destructive Testing (NDT) Techniques like inspection of deposits in tubes of different sections, hardness testing, Dye penetrate and ultrasonic testing of weld joints.
- Conduct destructive testing of sample tubes during overhaul of boiler. If defects are found, or a tube cracks or ruptures, repairs should be made by replacing all or part of the tube. It is sometimes necessary to plug a tube as a temporary repair until a regular maintenance shutdown occurs.
- Follow OEM recommendations for inspecting and maintaining Emergency Stop Valves (ESVs), Control Valves (CVs) and Non-Return Valves (NRVs).
- Boiler Tube Assessment – Conduct Ultrasonic, Metallographic Studies, Random Thickness measurement, Tube deposit analysis.
- Burners – Conduct visual inspection of nozzle assembly tips and clean if needed; replace nozzle tips and coal pipe bends as required.
- Internal inspection of Drum should include as a minimum the following:
  - Tightness of all drum internal parts should be checked.
  - Scrubbers and separators must be checked and be firmly in place to ensure the proper water/steam separation will take place.
  - Separators should be examined for any sign of erosion or corrosion.
  - Screens above the cyclone separators should be firmly in place.
  - The entire drum should be examined for deposits of any kind. Copper deposits, for example, could come from the feedwater heaters, condenser or other proud metal components in the water/steam cycle. Heavy copper concentration can lead to hydrogen embrittlement in the steam generator water walls or other high heat input areas.
  - Any unusual deposits found should be analysed, and follow-up inspections should determine that corrective action is being taken by the utility along with the feedwater treatment specialist
- Inspection and testing of the safety valves using Trevi test.
- Rotary Fans – Conduct inspection and replace blades if required.
- Conduct Boiler Hydro as per IBR: 1.25 working pressure once in a year and overhaul at least biannually
- Conduct regular monitoring of tube thickness, tube scanning using LFED (Low Frequency Electrodynamics Device).
- Conduct Remnant Life Assessment (RLA) of boiler as per OEM guideline.
- Always check for the leakages of steam, water, air and flue gases from any suspicious place.
- All instruments used for various critical measurements w.r.t temperature, pressure, flow must be calibrated at specified intervals of time.
- Ensure cleaning of boiler tubes during shutdown to prevent any ash deposition or scaling inside or outside the tubes. Failing to do so will affect boiler efficiency and will eventually overheat the tubes leading to tube leakage problems.
- Maintain the ratio of primary and secondary air in accordance with fuel feed as specified by OEM.
- Periodically check burner operation back pressure and line pressure to prevent any thermal hazard.

With recent catastrophic losses in boilers in various parts of the country, Central Electricity Authority (CEA) had issued following Advisory on Safety Aspects in Thermal Power Stations.

- Control loops of all major parameters of Unit operation should be commissioned.
- All systems of Unit including Control & Instrumentation (C&I) should be completed before commissioning/ COD.
- Subsequently Unit should operate on sustained basis without use of any contingency arrangements.
- All Soot Blowers must be commissioned and readily available for operation.
- Accumulation of Ash at S-panel, additional measurement with interlock trip on High level
- Ash handling at Economiser, Bottom ash, ESP to be verified thoroughly in design stage.
- No Manhole at bottom of the furnace should be opened while unit is operating.
- Water injection for dislodging of ash build-up over furnace bottom should be avoided.
- Qualified Boiler Operation Engineer (BOE) should be engaged in boiler operation.
- Develop Specific SOP for Critical Operations.
- Dedicate a Shift-Charge Engineer if Unit is distantly located.
- Operators working at ash handling areas must be provided with thermal suit which can withstand high temperature.
- Control room logbooks must be filled in proper manner indicating prevailing status of key parameters without any ambiguity.
- Maintenance department should not resort to any activity when boiler is in operating condition; endangering human safety.
- While attending any problem during boiler operation, clear practice of having a checklist for the safe practice should be adopted.

Guidelines

Following codes and standards can be referred for further reading:

- ASME Boiler and Pressure Vessel Code BPVC-1.
- National Board of Boiler and Pressure Vessel Inspectors Code—governs inspection, repair and alteration of boilers and pressure vessels after placed in service.
- Boilers and pressure vessel operations are strictly regulated within jurisdiction of states, municipalities, at respective Indian States.
- Synopsis of boiler and pressure vessel laws, rules, and regulations are available from Uniform Boiler and Pressure Vessel Laws Society.
- National Fire Protection Associations Boiler - Furnace Standards: NFPA 85A–8.

Engage

Answer the following questions and win **amazon** coupons worth INR 500.

Send in your answers to editor.bulletin@tataaig.com. Five winners for this Quiz will be announced in next issue.

Q1. What is the size of coal particle used as fuel in Pulverized Coal Boiler?

a) 50 microns
b) 75 microns
c) 100 microns
d) 200 microns

Q2. Hydro test of boiler is done at pressure which exceeds design pressure by

a) 1.25 times
b) 1.5 times
c) 1.7 times
d) All the above

Q3. Overhaul of Boiler should be done as least once in

a) 06 months
b) 01year
c) 02 years
d) 03 years

Winners who have send the correct answers for Quiz questions of previous issue are

- Ajeet Phatak – MunichRE, Mumbai
- Girish Gangadharan – GIC of India, Mumbai
- Lathisia Aruna – J B Boda, Bengaluru
- Ravi Varma K – Marsh India, Hyderabad
- Darvesh Panchal – Prudent Brokers, Gurgaon

Answers to Quiz questions of previous issue are

1. Water   2. All the Above   3. All the Above

For feedback or comments related to this bulletin, please write to editor.bulletin@tataaig.com

Editor
Nanda Kishore Danduprolu
AVP and National Head - VAS and Risk Engineering
nandakishore.d@tataaig.com

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Tata-AIG General Insurance Company Limited
Peninsula Business Park, Tower A, 15th Floor
G. K. Marg, Lower Parel, Mumbai 400013
www.tataaig.com