Design and maintanance aspects for prevention of pressure part failures in sugar plant steam generators

S.Sridharan

INTRODUCTION

Industrialisation process is closely linked with the production and distribution of thermal energy. Even the other forms of energy like electrical energy have their origin to a great extent on production of thermal energy. While heat can be used in certain industries directly from the products of combustions, most of the industries rely on steam as the carrier vehicle for their thermal energy requirements. Sugar industry uses large quantities of steam, making them most suited for adoption of co-generation. The typical quantities of steam consumed by various Indian industries are shown in Table (1).

India produced 300 million tons of sugar cane during 2001-02 and hence was burning around 90 million tons of bagasse during the same year for steam generation, producing around 200 million tons of steam. At the price levels of 2002, the cost of production of steam in India is around Rs.200/- tonne. Thus, even a 10% fall in production of steam every year would mean a financial loss of Rs.400 Crores of rupees. Since steam is used for producing various other industrial products, the fall in industrial production because of steam generator failures will be even higher.

A steam generator generally has two important duties. The first one is to release heat from the fuel. This process is termed as combustion. The second one is the main process of generating steam, which is achieved through heat transfer. All the components of the pressure parts of the steam generator are involved in either one or both these duties. The pressure parts perform their duties in an environment of intense heat flux, high mechanical stress, corrosive and erosive atmosphere as well as high temperatures. It is therefore necessary that these components are selected and used with due regard to their environments.

The furnace enclosure is formed by water wall tubes. These tubes are subjected to two phase heat transfer and often suffer heat fluxes of 150000 kcal/m2.h or more. There are also occasions when these tubes are subjected to film boiling conditions. The tubes require special design features to accommodate the linear expansion they suffer during operation. The boiling heat transfer of the tubes can also create scaling problems on the inside of the tube. Thus the water wall tubes are the most vulnerable pressure part in the entire steam generator.

The superheater tubes have a different set of problems because of their location in high temperature zones. Even though the heat flux in superheater region rarely exceeds 70000 Kcal/m2.h, the film co-efficients on steam side are relatively lower, leading to higher tube wall temperatures. The use of alloy materials for superheater tubing brings in the need for more sophisticated welding procedures. Some of the tubes kept in the gas temperature zones of 1000 to 800ºC are also susceptible to high temperature corrosion especially if the boilers use furnace oil firing frequently.

The economisers are compact heat recovery units used for imparting sensible heat to the incoming feed water. As their very name implies, they have to be cost effective and hence follow a design of compactness with high heat transfer co-efficients. In addition, since they are located downstream of other pressure parts, they are susceptible to gas flow separation problems. The economiser tubes are normally bent to close radii which can result in the thinning of the tubes at the bends, making them more vulnerable for erosion.

All the above pressure parts are thus susceptible to failure. However the operational statistics show that the water walls are the most susceptible pressure part component for failure. This is illustrated from the data shown in Table (2).

TYPES OF FAILURES

Even though all pressure parts ultimately fail because of the material not able to withstand to stress due to internal pressure, there are several primary causes for these failures. The primary failure causes are described below:

Improper Water Chemistry: In India the water wall tube failures due to improper water chemistry assumes very severe proportions. The problem is more pronounced in industrial steam generators, even though they work at relatively lower pressure regimes as compared to their utility counter parts. Even very small amounts of dissolved solids in the boiler water accumulates to serious proportions during the course of time. Typical feed waters with as little as 5 ppm dissolved solids (compare this with very good domestic potable water containing 150 to 200 ppm of dissolved solids) can leave behind a quantity of 3 tonnes of residue in the water wall tubes of a steam generator of 100 tonnes per hour capacity during the course of one year's operation. The solids should therefore be flushed out of the boiler regularly by blowdown. However if the feed water chemistry is faulty, these dissolved solids would form hard scales on the water wall tubes instead of getting flushed out. A calcium scaling of 0.5 mm thickness on the water wall tubing is sufficient to raise the tube metal temperature beyond safe limits resulting in tube fusing, metallurgical transformations in the heat affected zone as well as slag inclusions and porosities are some of the weld defects leading to failure. Improper design of weld joints and choice of welding procedures have also known to cause tube failures.

High and Low Temperature Corrosion: The chemical action of the environment in which the pressure parts are working, results in corrosion of metal and consequent failures. Fuels containing sulphur, vanadium and sodium are potential sources of metallic corrosion. The sulphur-di-oxide produced from combustion of fuels is known to preferentially attack metals at temperatures of 550 to 750ºC when there is a presence of vanadium and sodium. The eutectic compounds of vanadium tend to lower the melting point at the joints of metals used for tubes, resulting in sulphur attack and corrosion. This is termed as high temperature corrosion.

The fuels containing sulphur and water vapour give raise to a different type of corrosion problem. Depending on the percentage of sulphur, moisture present in the fuel and the percentage of excess oxygen in the products of combustion, there exists a temperature below which, sulphuric acid is generated from the flue gas which condenses on the surfaces. This temperature is normally referred to as the 'dew point'. The economiser is a pressure part which is highly susceptible for the dew point corrosion from free sulphuric acid. This is termed as the low temperature corrosion.

DESIGN FEATURES FOR FAILURE PREVENTION

The consequence of pressure part failure and the reduction in availability of steam generators cannot be over emphasised. Every possible care is to be taken at the design stage itself to avoid such failures.

The most important thing is to prescribe the correct feed water quality at the design stage itself. The safe recommended qualities for feed and boiler water are shown in Table 3.(4) Depending on the prescribed quality, the raw water will have to be either merely softened or demineralised. Proper deaeration of the feed water to reduce the residual oxygen content in feed water to below 0.01 ppm is necessary, especially in steam generators working at 41 kg/cm2 pressure and above. Dosing the feed and boiler water with hydrazine and trisodium phosphate or other volatile agents are to be prescribed.

The maximum possible tube metal temperatures should be routinely calculated for superheater tubing and the tube thickness and metal should be chosen accordingly. Thus it is very important to maintain the feed water properties with in strict limits. Some of the boiler operators try to quickly establish the required feed water alkalinity (after a lapse) by excessively dosing the water with caustic soda. Such practices, even though may save face for the present, can lead to problems of caustic hideouts and tube metal failures because of embrittlement. Insufficient deaeration of feed water is a known cause for water wall tube failure in small steam generators. The free oxygen present in feed water leads to the tube wall corrosion and consequential failures.

Over Heating of Tubes: The design of pressure parts requires proper estimation of the tube wall metal temperatures under various operating regimes. Even small deviations of the order of 25º C from these estimated values, can cause operational failures in the tubes designed for creep rupture. The tensile strength and residual life of tubes working at high temperature can be assessed by the Larsen Miller Method (3). These methods are useful in judging the residual life of tube material which have drifted into operation regimes with higher than rated temperatures. The creep phenomina results in weakening the inter crystalline bonds and in permanent elongation. This results in reduced working life of the tubes. There is however another distinct group of failures due to overheating when the tube metal is subjected to significantly higher (of the order of 100º C higher than the design value) temperature excursions. The tube failure in such cases occur within a short duration of the deviation and hence such failures are termed as due to short term overheating. Both the modes of overheating can occur either due to faulty design or due to faulty operation methods.

Erosion and Rubbing of Pressure Parts: Special problems emanate from the use of solid fuels like coal. The ash in solid fuels is a source of erosion from the gas side on the tubes. The constituents of ash from most of the Indian coals are Silica and Alumina. These materials are known for their high hardness. When they travel with the flue gases across pressure part tubing, they tend to severely erode the tube surfaces. The metal loss due to erosion from the tube surface is proportional to the 2.5 th exponent of linear velocity of the gases. Thus, even small increments in gas velocities due to flow segregation and eddies can cause severe damage to the pressure part tubings leading to thinning of the metal and causing failure. Undue gas velocities bring flow induced vibrations leading to chattering and rubbing at mechanical fixings. Such situations lead to failure from metal fatigue as well as galling.

Weld Defects: Modern steam generators rely to a very great extent on welding for fabrication. A typical bagasse fired steam generator of 70 t.p.h rating uses as many as 3000 shop and 1500 field weld joints on the pressure parts. The quality requirements of these welds are very high since failure of any one of these joints can lead to unit shut down. In order to avoid flow disturbances because of weld root bumps on the inside of the tube, critical tubes should be welded with TIG root. Correct edge profiles must be prescribed for every weld to ensure good welding without slag inclusions or porosity. The provision of inter stage headers on superheaters should be chosen with proper relevance to the system pressure drop to avoid steam flow inbalances leading to flow stagnation / segregations.

Location of heating surfaces immediately after sharp turnings in the gas path should be avoided. Where this becomes a necessity, the aerodynamics of gas flow across such heating surfaces should be analysed and necessary baffles and turning vanes be installed on the gas path to prevent flow segregation leading to undue erosion of pressure part metals.

Whenever the feed water entry temperature to the boiler is less than 140º C, due care must be taken to prevent low temperature corrosion of economiser tubes. On specific cases, special copper alloy bearing material should be chosen to prevent or minimise low temperature corrosion.

In the unfortunate event of a pressure part failure, it must be possible to quickly repair the defect and bring the steam generator back again on line. The "mean time to repair" a failure is to be kept as low as possible by the provision of adequate repair space between banks of heating surface and also providing quick access to the header tube connection points. The achievable mean time to repair various pressure parts (after a failure at full load) is show in Table 4.

OPERATIONAL FEATURES FOR FAILURE PREVENTION

Even the best designed steam generators have gone down the drain in some occasions, when proper care is not taken in operation and maintenance.

The most important operation prescription would be to strictly adhere to the recommended feed and boiler water qualities. Similarly improper control of the combustion air (forced draft) fan leads to unduely high excess air operation leading to unexpected failures due to erosion.

Many pressure part failures have occurred because of bad boiler startup methods. The firing rate should be carefully controlled (during start up) with liberal draining and venting from various headers so that all the components are properly cooled by the flow of water and steam.

The gas temperature prescriptions at various locations during start-up should be strictly adhered to, by manipulating the combustion and water feed regime.

The plant control rooms are normally provided with adequate indicating and recording instruments for the process parameters. The shift engineer in-charge of operation, should ensure that these parameters are logged at definite intervals and the information so obtained should be carefully analysed. Many a costly failures were prevented on many occasions by such a practice of data logging and analysis.

SUMMARY

Steam generators are costly equipments and provide the work force for the main process of the sugar industry. The ' availability' of steam generators is therefore very important to maintain production. A proper understanding of the causes of pressure part failures and the methods of preventing the same would go a long way in increasing the production and productivity of various industries and thermal power generation.

REFERENCES

1. Process Steam Users Technical data - Suvens Technical Press - Madras - 600 018.
2. Allianz Handbook of Loss Prevention - VDI verlag Ag - Germany
3. Metallurgical failures in Fossil Fired Boilers - Wiley Interscience Publications.
4. Boiler Handbook - Bharat Heavy Electricals Limited - Tiruchirappalli - 14.