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WARRANTY RELIABILITY OF CFB BOILER BURNING OIL SHALE

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Reliability of power plants is one of the primary concerns in power industry. Usually the reliability of boilers is calculated on the basis of analysis of long-term operation data or using the data of short tests by extrapolating them to long-term operation. Short tests in laboratory conditions can provide the data for initial determination of boiler reliability by the method of extra polation, but finally reliable data must be confirmed by industrial operation. Data on unit operation are obtained during the warranty period, which started after provisional acceptance conditions have been met, when the unit starts normal operation. The failures of components of CFB boilers that became evident during the warranty period are analyzed in this article.

Introduction

Operational and maintenance records for warranty reliability and all other maintenance-related actions during the warranty period can be extrapolated to the long-term operation of the unit, thus eliminating the need for laboratory tests. When using the "warranty time based" method for establishing reliability requirements for the boiler, in most cases it will be possible to determine the overall reliability.

Over 80% of all lifetime costs are defined and determined during the equipment design and development phase [1]. In real terms it means that the main opportunity and responsibility for reducing lifetime costs of a power production unit relies on the equipment manufacturer. Data on quality of elements, engineering, erection and used technique obtained during the warranty period allow the determination of reliability of the unit.

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All damages, including also damages arising from operation negligence or willful misconduct, or from the effects of normal wear and tear in the warranty period influence reliability of the unit.

Atmospheric circulating fluidized-bed (CFB) technology has emerged as an environmentally acceptable technology for burning a wide range of solid fuels to generate steam and electric power. CFB, although less than 20 years old, is a mature technology with more than 400 CFB boilers (energy units ranging from 5 to 320 MW_{el}) in operation worldwide [2, 3].

During the last few years CFB technology has faced the challenge to achieve high levels of reliability when using cheaper ("hard to burn") fuels. Burning the fuels whose mineral matter content is high and calorific value is low in CFB boilers, specific requirements for reliability of boiler arise.

Even though pulverized combustion (PC) boilers continue to play a major role worldwide, they have inherent shortcomings such as fuel inflexibility and environmental concerns.

Compared to PC burning, due to the use of poor fuels (low calorific value, high ash content), the requirements for CFB boiler parts and systems are stricter, and also due to the differences in burning technology special additional systems are needed. Advantages of a CFB boiler (<150 MW) in comparison with PC boilers are listed in [2, 3]. Most of comparable items show CFBs to have benefits and advantages; only capital costs for CFB are higher than those for PC boilers. As for the benefits, considering the circumstance that the warranty period is relatively short in comparison with the total lifetime of boiler, warranty reliability is affected by fuel particle size (fuel crushing cost is reduced at CFB) and O&M (cost of CFB is less because of less moving equipment compared to PC). Both advantages depend directly on the fuel combustion method.

Therefore, the aim of the work was to establish reliability of the unit basing on the analysis of actual data obtained during the warranty period.

Failure analysis

Failure analysis of CFB oil shale boilers was made according to the method [4] based on the following points: typical location of failure, probable root causes and their verification, typical appearance of failure, and evaluation method. In practice the final action for eliminating the failure was remedy work in power plant.

During the warranty period it was guaranteed that the availability of the boiler plant will not be less than 96% defined as follows:

$$A = (T_a - T_{po} - T_{uo})/(T_a - T_{po}),$$

where:

T_a – total hours of the availability period,

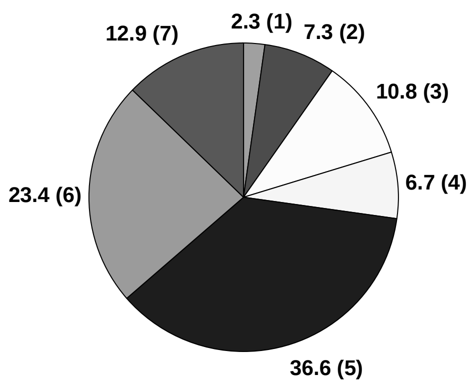
T_{po} – total planned outage hours when the plant is out of operation due to scheduled maintenance or maintenance,

T_{uo} – total unplanned outage hours when the plant is out of operation due to unscheduled maintenance.

During the warranty period there were less than 300 defects recorded for four boilers without the defects related to turbine and its equipment. The number of presented warranty items which had affected unit reliability significantly depended on human factor. For example, operational personnel fixed many defects during the operation of the boilers or during the scheduled outage, and these defects did not decrease warranty reliability, i.e. there was no unscheduled maintenance with shutdown of the boiler. These kinds of problems occurred in mechanical, electrical and instrumental areas, numerously in instrumental and electrical area – 125 positions. Most of these kinds of defects (45%) concerned changeable and wear and tear parts.

The distribution of defects in Fig. 1 is as follows: 1. Defects concerning boiler – pressure parts and refractory (2.3%)**.** 2. Defects in the fuel and bed material supplying system (7.3%). 3. Defects in the ash removal system (10.8%). 4. Defects in the rotating equipment (6.7%). 5. Defects in electrical and instrumentation systems (36.6%). 6. Defects related to the turbine equipment (23.4%). Similarly, relatively as much defects were found in the turbine in [5]. Other defects are mechanical (valves, building, etc. 12.9%).

The scheme of the boiler and some defective places found during the warranty period are shown in Fig. 2.



(1) pressure parts and refractory;
(2) fuel and bed material supplying system;
(3) ash removal system;
(4) rotating equipment;
(5) electrical and instrumentation systems;
(6) turbine equipment;
(7) others – mechanical, valves, building etc.

Fig. 1. Distribution of defects, %.

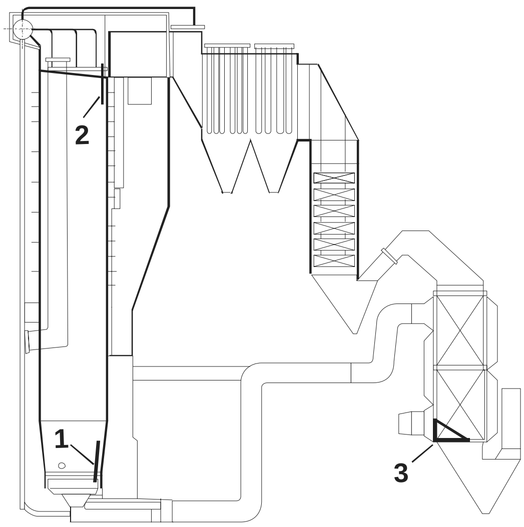


Fig. 2. Scheme of boiler and defective places. 1 – broken canopy, 2 – separator leakages, 3 – damaged air preheater.

Boiler – pressure parts and refractory

Failures of pressure parts during unit operation forced the shutdown of the boiler for carrying out remedy works. As the warranty period is relatively short compared to the designed lifetime of the boiler, the failure inside this period cannot result from a long-term process, but has to be a manufacture-based phenomenon.

This assumption has been confirmed by the finding that two leakages were discovered in separators of different boilers (Fig. 3). Nonqualified welding between tube and rib on the bent of steam-cooled separator tubes caused developing a crack penetrating tube walls. Annual availability of the boiler was affected due to failures at which outage times for remedy works varied from 72 to 96 hours, approximately 0.45–0.6% of the total availability decreasing warranty reliability.

Another kind of failures occurred in the furnace of boilers. On the contrary [5], when burning oil shale, damages in the refractory of steam-cooled separators were not noticed. Boiler operation had no destructive influence on the refractory of the walls, wing walls and return legs inside of the bed material, but there were cracks in the refractory canopies of solids' return channels, obviously, thermal expansion of the refractory of the furnace bottom and of the back wall being different. The upper parts of some canopies were disintegrated due to moving of the canopies' refractory (Fig. 4). Repairs or casting of new canopies were made during the planned shutdown without the ordered outage of boiler.

Strengthened ties between the canopy and the back wall avoided the following disintegration of refractory.

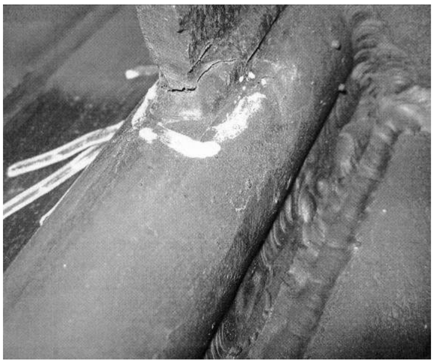


Fig. 3. Penetrating crack on tube walls (position 2, Fig. 2).

Fig. 4. Disintegrated refractory of canopy (position 1, Fig. 2).

Warranty reliability has been affected by low-temperature corrosion of the tubes of the air preheater (position 3 in Fig. 2). Intensive corrosion of the tubes was unexpected because there was no usual aggressive corrosive matter such as sulfur compounds in deposits on the tubes. Obviously intensive corrosion was related to elements such as Cl, Ca, K present in compounds found in deposits.

Replacement of the damaged tubes and improvement of the technology by preheating the air were carried out and implemented during the planned shutdown without the ordered outage, but shutdown time increased by 720 hours, i.e. 9% of the total availability.

Fuel supplying system

In these systems the damages have been resulted from wearing the elements due to moving of the erosive matter in the fuel system (positions 4, 5 and 6 in Fig. 5).

Discs of the secondary crusher (3) have broken due to the presence of foreign metallic substances in the fuel flow. This had happened irregularly, but averagely once in month. If one crusher is stopped for the replacement of broken discs, fuel flow is distributed between the remained three crushers. Failure of that kind and proper action – replacement of the discs – has not required any forced outage of the boiler.

Erosive wear due to high hardness of fuel particles in the fuel path is significant [6].

Erosive wear of the corrugated wall with thickness 2 mm (4) was avoided by correction of the construction, but erosive wear of the inclined elements (6) after 2000–3000 hours and (5) after less than 8000 hours were regular due to abrasive action of fuel flow. Such a wear is characteristic of such kind of fuel transportation in the case of the present combustion mode.

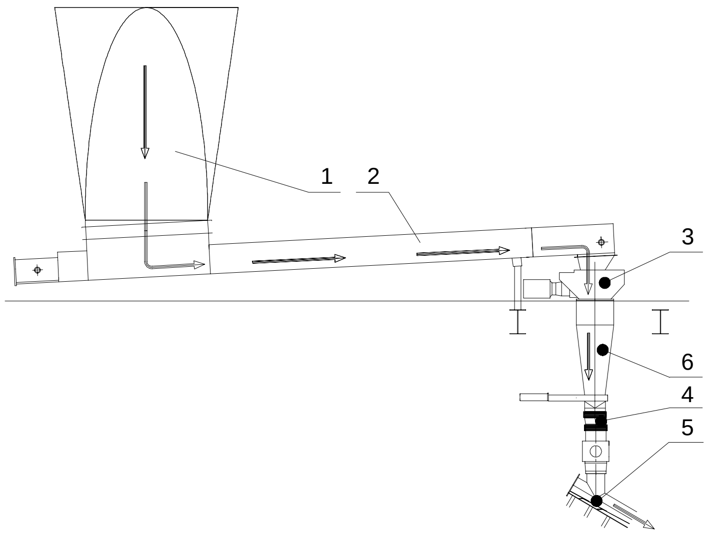


Fig. 5. Fuel supplying system. 1 – bunker of fuel, 2 – conveyor, 3 – crusher, 4 – compensator, 5 – inclined chute, 6 – vertical canal.

Damages in slightly inclined walls were eliminated during the operation without boiler outage, because the damages marked at (6) occurred in one line of the set of eight for one boiler.

Damages on fuel chutes (5) were repaired during boiler shutdown – once a year. As shutdown of the boiler has taken place every year, the ordered outages of boiler are made twice during the warranty period.

Erosion of sand supplying pipelines was observed during the time of boiler commissioning. Particularly strong erosion took place at the bends of pipelines; frequently erosion damages penetrated pipe walls. Repairing of damages did not necessitate any ordered/forced outage, because filling of the bed material silo normally took place before the start of the boiler. During the operation of the boiler there is no need to fill bed material silos, because the necessary amount of the bed material is formed from oil shale ash.

Damaged elements requiring improvements in the fuel and bed-material systems were design-based bottlenecks, and did not necessitate any forced outages. In practice the removable parts have been taken into account as normal wear and tear parts.

Consequently the failures described above did not decrease warranty reliability.

Bottom ash removing system

Failures, which affected warranty reliability of the bottom ash system equipment, were mainly caused by two factors – high amount and high temperature of ash.

Temperature of ash is up to 800 °C in the ash outlet from the furnace. The ash is cooled by water running in the screw shaft and external crust of the screw conveyor. The ash cooled down to 400–500 °C falls onto the horizontal scraper conveyor where it is continuously cooled down by cooling water in the central plate and on the bottom of the conveyor case. Temperature of ash at the end of the conveyor is approximately 100–120 °C. Excessively high temperature of ash has been the reason for frequent degradation of pressure and capacitance sensors of ash cones and ash bunkers in the ash removing duct. Quantity of ash per conveyor was 10–15 t/h.

Typical damages were cracks in the welding seams due to thermal expansion between different parts of the equipment. Repairing of the cracks did not require shutdown of the boiler.

Failures of other kinds occurred in the non-cooled chain stretcher (Fig. 6) which stretches the chain to turn at an angle of 159°. The stretcher consists of the shaft, bearings and the tail wheel. Working conditions of the stretcher were complicated as high temperature of ash and sometimes overload of scraper caused the breakdown of the assembly. There were damages of bearings, intermediate bushings and packing housing, and the damages of shaft. The lifetime of the assembly changed from 5040 to 13 600 hours – in average from one to two years.

Replacement of the stretcher assembly did not necessitate outage of the boiler, only shutdown of the failing conveyor. During improvement of the stretcher by strengthening the construction, ash unloading from the furnace was carried out by the second ash conveyor, and it was recommended to decrease boiler load by 10–15%.

Failure of the stretcher of the ash conveyor did not decrease warranty reliability of the unit, it only decreased production of the unit and increased the expenses for repairing.

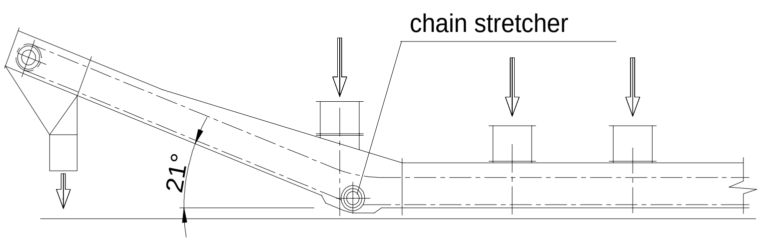


Fig. 6. Bottom ash conveyor.

Failure of rotating equipment

PC and CFB have the same rotating equipment as primary and secondary fans and pumps with different designation. However, CFB needs an additional special rotating equipment – high-pressure blowers. High-pressure blowers provide fluidizing air to the wall seals, to the INTREX chambers and to the bottom ash removal system as well as cooling air to the start-up burners. Three or four of the blowers are normally in service at a time and the remaining ones are in stand-by mode.

During the operation of the high-pressure blowers it was observed that failures had been started after some months of operation and occurred frequently. The failures were characterized by the cracks in welded seams, silence cases, and other elements. Work of the blower was accompanied by its high vibration – more than 20 mm/s.

Repairing of the cracks did not give satisfactory results, damages were still repeated. Investigations showed that vibration was caused by too light construction of the blower. After determination of the reason of vibration, the manufacturer replaced the blowers with strengthened ones.

While the boilers had enough redundancy with stand-by blowers, the boilers were not stopped for repair works.

Conclusions

Warranty period is a relatively short time for predicting the long-term reliability, but during this period it is still possible to predict locations and also mechanism of the first-time failures. As shown above, there were critical failures in pressure parts and components (ash-removing elements, tubes of air preheaters). Critical failures can arise from poor quality of manufacturing and erection (pressure parts), but also from poor technology (air preheater). Drawbacks of design (incorrectly chosen blowers) also affect warranty reliability.

Most of the above-noted failures were not critical issues during the warranty period, except of pressure parts and air preheaters.

Non-critical equipment can be improved by predictive maintenance. Predictive maintenance requires continuous monitoring of the equipment by plant staff and by automatic means. Necessity to replace defective instrumentation apparatus and sensors, and also welding of external wearing places on tubes can be determined by monitoring.

Warranty reliability is the dominating characteristic of the quality of design, manufacturing and erection.

The warranty-time operation did not show the necessity to use any new technical solution instead of advanced CFB technology for oil shale burning.

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