DETONATION-WAVE TECHNIQUE FOR ON-LOAD DEPOSIT REMOVAL IN COAL-FIRED BOILERS

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Introduction

The maintenance of clean surfaces in coal- biomass or waste fired boilers and furnaces is one of the major prerequisites for attaining the maximum guaranteed performance of thermal-power and industrial plants. Local washing of exposed surfaces with fluid jets (water and air soot blowers, steam lancers) is the most widespread methods for on-line cleaning of gas-side surfaces in large-scale installations. While generally regarded as satisfactory, fluid jet devices are known to produce nonuniform cleaning which, in addition to poor heat transfer, can lead to local damaging of tube surface due to strong abrasive and erosive effects especially when the fuel contains hard aluminum silicate compounds. [1]. The problem of nonuniformity can be diminished by applying soot blowers of sophisticated design with telescopic tubing and controllable rotating heads that can penetrate deep into the tube packages, but this technique is expensive, not applicable (or not suitable) for all types of boilers, and it is not always effective.

The Detonation Soot Blower (DSB) technique using detonation waves generated in an external wave generator possess all advantages of air-cannons, but it is easier to operate and to control, and it is also much less costly both in investment and exploitation, as proved by our thirty-years of experience. Besides, unlike air-canons, the detonation waves provide also a thermal shock which contributes further to deposit break up and removal. The entry ports of the detonation waves can be placed according to needs and waves can be directed towards the surfaces most prone to fouling. While one cannot claim that this technique is a panacea for all fouling problems, it has a number of advantages and its niche in boilers fired with solid fuels (coal, biomass, municipal and industrial wastes) of low-calorific-value, high content of mineral constituents and ash characteristics that makes it prone to agglomeration.

We report here on the close-to thirty years experience in using the detonation wave technique in two coal-fired boilers in the Thermal Power Plant “Kakanj” in Bosnia, as well as on some recent developments. Although of different types, both boilers are of the same capacity with nominal steam production of 340 t/h, each driving one steam turbine–electric generator of 110 MWel. The technique, developed and tested initially in a laboratory-scale boiler model prior to its installation in the full-scale plant, is described in Hanjalić and Smajević, [1], [2]. Over the years, several modifications have been made which improved the economy and reliability of the detonation-wave generators and made their maintenance easier. These involved reconstructions of the detonation-wave generators, relocation of the shock-wave entries into the boilers with the installation of protective aerodynamic valves, and others. The technique was recently installed and tested in a boiler of 980 t/h steam production in a power plant in Germany, and is planned to be installed also in another larger boiler of 760/610 t/h in the Kakanj plant. We present here some features of the technique, results of boiler performance monitoring and discuss some issues raised in regard to possible negative effects on boiler interior walls and its structure.

The idea to search for alternative boiler cleaning methods in the coal-fired Thermal Power Plant "Kakanj" in Bosnia emerged in the early eighties after experiencing insurmountable problems with heavy fouling and ash agglomeration, especially in the convective tract in two boilers of 340 t/h nominal steam. Despite the regular daily use of 18 steam soot blowers provided by the boiler manufacturer, the problem became intolerable: the boilers performance deteriorated steadily and every couple of months the operation had to stop in order to remove manually large amount of hard deposit, as well as to repair for leakage or to replace a significant number of tubes or their parts (especially the U-bends). After screening possible use of sonic horns and air cannons, we opted for a new technique based on the action of detonation waves. Some, though very limited, information about the use of pressure-waves for cleaning gas-side surfaces in waste-heat boilers in iron- and copper smelteries could be traced in Podimov et al. [4]) and Schelokov et al. [5], though the methods described were based on pulse-combustion rather than detonation waves.

After some preliminary tests in an old 110 t/h Steinműller boiler in cooperation with the Institute for Thermal Equipment (VUEZ) in Tlmače, Slovakia (the manufacturer of both 340 t/h boilers here discussed), it became obvious that only a thorough experimental investigation at a laboratory scale can provide information necessary for optimum design and exploitation of the technique. The issues to be investigated were related to the optimum design of the detonation wave generators that should ensure safe and controllable daily operation over a long period in harsh industrial conditions. Other issues to be clarified were related to the formation of waves and their propagation through the connecting piping system, and the dynamics of wave reflection and attenuation after entering the boiler interior. The key question concerned the optimum wave strength that would ensure sufficient impact to break up and to remove the deposited material and yet not to cause any damage to the boiler interior structure, piping and, especially, to the refractory walls. The investigations conducted at the University of Sarajevo in the period 1981-1984 provided most information needed and showed very encouraging results [1]. The technique was subsequently installed in the full-scale plant. The first full-scale daily operation of the DSB technique in a relatively new coal-fired steam boiler (hereafter referred to as Boiler I) began in 1983. The effects of this – at that time very new technique - were immediately visible: the fouling was significantly diminished and could be controlled to enable normal plant operation without frequent interruptions and with expected steam production and acceptable general plant performance.

After several modifications and extension from two to three detonation chambers, the authorities granted the official approval of the technique in 1987. The technique was subsequently installed into another boiler of the same capacity and similar configuration (hereafter referred to as Boiler II). Unlike the first boiler with fully screened interior with tubes and steel plates in between, the second boiler was considerably older, with interior made of heavy refractory walls. No negative effects were noticed over the years in any of the boilers, despite regular use of detonation waves two or three times per day. Since then, the detonation-wave technique has been in continuous use as the standard cleaning technique in the plant.

Several modifications were introduced over the years leading to improvements, as illustrated below by several monitoring indicators. The three-decades of monitoring of the boiler interior walls, its structure and piping showed no negative effects.

Deposit removal mechanism

The major effect on the break up of the material deposited on tube packages and other boiler interior surfaces comes from the mechanical shock. The first obvious effect is the excitation of vibrations of the tubes and boiler walls, which in turn loosens the deposited material. This effect depends on the size and configuration of tube package and surrounding walls, as well as on the amount and properties of the deposited material. The next main contribution comes from the direct impact of the shock on the deposit, which depends on the intensity of the wave and the angle of attack with respect of the exposed surfaces. It is impossible to ensure uniform intensity of the impacting wave on all surfaces, especially deep in the tube package irrespective of how many wave entries are provided, though their positioning and orientation can and should be optimized. Fortunately, waves reflect from solid surfaces and propagate in all directions penetrating the inter-space between the tubes and impacting on most of the exposed surfaces, though not with the same intensity. It is not, however, the original impacting wave itself that produces the largest cleaning effect, but rather a sequence of compression and rarefaction waves in the deposited material, which cause the loosening of the cohesive bonds in the deposit. The impacting compressive wave penetrates the deposited material and reflects from the solid (tube or wall) surface again as a compressive wave towards the deposit free surface, from which it reflects as a rarefaction wave, and so on, Fig. 1. These prolonged effects, and especially the internal rarefaction waves that cause the tensile stress in the deposit, are believed to be the major mechanism of deposit destruction, especially if its material is not very hard.

The impact of a shock wave on the exposed surface is the main, but not the only effect that causes the break up and removal of the deposited ash. Much of the effect can be attributed to the thermal shock that imposes thermal stress and weakens the cohesive forces between the deposited material and adhesive forces between the deposit and the tube surface. The thermal shocks are especially effective in the convective portion of the boiler where the temperatures of the flue gas and the fluid inside the tube packages is relatively low (economizers and air preheaters). This feature distinguishes the detonation wave method from air cannons or otherwise generated non-reacting shock waves. Other contributions come from the direct washing away of deposit by exhaust gases from the detonation chamber at the expense of their kinetic energy, interaction of these gases with the mainstream flue gases, vibration of tubes and boiler walls due to mechanical shock, and others. More details can be found in Hanjalić and Smajević [2], [3].

Full-scale exploitation and monitoring experience

We reported earlier in details on our experience with full scale operation in two boilers, [1]-[3]. Altogether 5 detonation wave generators (3 for Boiler I and 2 for

Boiler II) with total 12 wave entry ports (8 in Boiler I and 4 in Boiler II) have been used, connected to the same air and fuel supply. For each boiler a separate control unit was provided making it possible to generate automatically a series of 8-15 detonations with half a minute intervals. The entry ports in Boiler I were all placed on the ceiling of the convective (second) shaft and in the duct connecting the furnace with this shaft. In Boiler II the entry ports were placed on the side walls of the inter-space between the superheater and the economizer. Originally the reason for side positioning was the inaccessibility of the ceiling in Boiler II, but this practice proved to be beneficial and practical and was subsequently applied also in Boiler I, as discussed below.

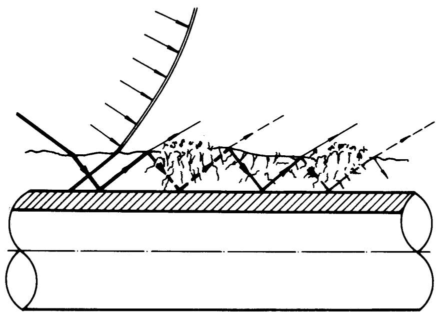


Fig. 1 Schematics of shock action on deposit breakup. Solid lines: compressive waves, dashed lines: rarefaction waves.

Fig. 2 A view of the refractory wall around the wave entry port above economizer tube package after 15 months of continuous operation of DSB.

The major concern of the plant management were possible long-term negative effects on boiler structure and its interior walls, especially in Boiler II with refractory interior lining. This concern proved to be unfounded. Experiments in the laboratory-scale model showed that the intensity of the original detonation waves attenuated dramatically after entering the boiler space. For example, in the laboratory model the wave crest pressure in the guiding tube of 15 cm in diameter before entering the boiler space was of the order of 15 bars, to drop to about 2 bars immediately after the entry in the boiler model of 2×2 m in the cross section. The waves weaken further in the course of wave propagation through the model boiler [1]. In real full scale boilers the expansion ratio is much higher than in the experimental boiler making the wave intensity in the boiler space of only a fraction of a bar gauge. However, the best proof that the technique was benign to the boiler structure was the in-situ test. We conducted a series of tests by careful visual inspection of the refractory wall surface during the boiler maintenance over a longer period. Slight damages of the wall surfaces were occasionally noticed, but not more frequently and not more severely than before when no DSB were used. Figure 2 shows the interior space between the superheater and economizer in Boiler II after 15 months of continuous daily operation of DSBs. This is the most critical area because of direct exposure to waves from the wave entry port, as seen in the figure: no sign of any cracks or damages is visible. Note the superheater (above) and the economizer tubes (bellow) with only slight deposit on the rear side, but clean surface on the front and free gas passages. It should be noted that the wave entry ports are directed under an angle downwards towards the economizer tube package, Fig. 2.

In order to estimate the true cleaning effects, two tests were undertaken in succession, each lasting about three months. During the first test the original 18 steam soot blowers were used every 8 hours. During the second test, only 6 steam blowers were operated in the furnace, while the all 12 steam blowers in the convective shaft were shut down and cleaning was performed with the detonation soot blowers.

The effect is clearly seen in Fig. 3 showing the recorded temperature of the flue gas and the steam production. During the use of steam soot blowers (empty symbols) the flue gas temperature showed a steady increase accompanied by a steady decrease in the steam production. In contrast, the application of detonation waves ensured very steady behavior (after some initial adjusting period) of the boiler performance over the whole test period. For reference, the coal calorific value is also shown for both periods to eliminate any possible effects of the coal quality on the boiler performance.

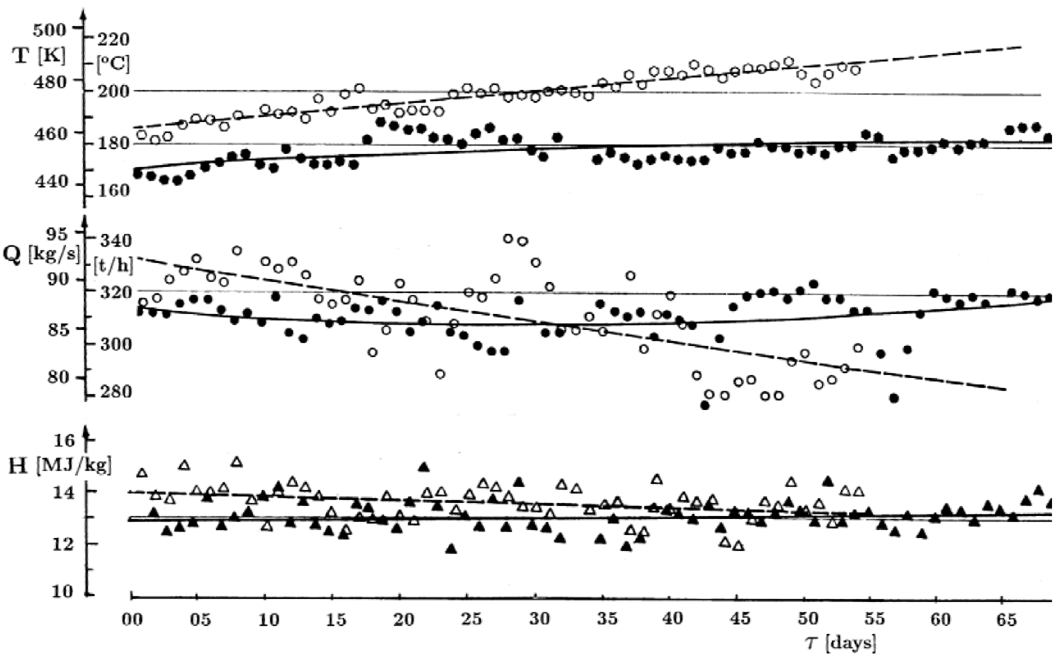


Fig. 3. Flue gas temperature, steam production and coal calorific value over two successive test periods: empty symbols: steam soot blowers; full symbols: detonation waves.

In order to get a deeper insight into the effects of DSB in various parts of the boiler, detailed monitoring was introduced by recording several parameters immediately prior and after the application of DSBs. The temperature of the flue gases was measured in both the left and right boiler tracts at several indicative locations: in front of the second inter-superheater, in front of the economizer and at the boiler exit (entry to the chimney). The temperature drop is a good indication of the heat transfer efficiency, which of course deteriorates with fouling. The measurements at locations in both trackts showed a decrease in the temperature indicating a cleaner surface and, consequently, better heat transfer [4]. The measurements demonstrated the effect of one cleaning procedure, which usually consists of a series of about 6-10 detonations. Other parameters were also been monitored such as total steam production, vacuum at the boiler exit, power of the flue gas ventilator (also an indicator of the intensity of fouling).

The positive experience with the side wave entries in Boiler II and difficulties with the maintenance of the wave entries on the ceiling of Boiler I have lead to the installation of the entry ports on the sides also in Boiler I. The new and additional detonation wave generators with improved design have been installed in Boiler 1 (now four in total). Next to the two wave generators placed in the space before economizer, two additional ones were installed in 2003 in Boiler II, with entry ports in the superheater track. A view on one of the boiler and its schematics are shown in Fig. 4 indicating the detonation generators and locations of wave entries.

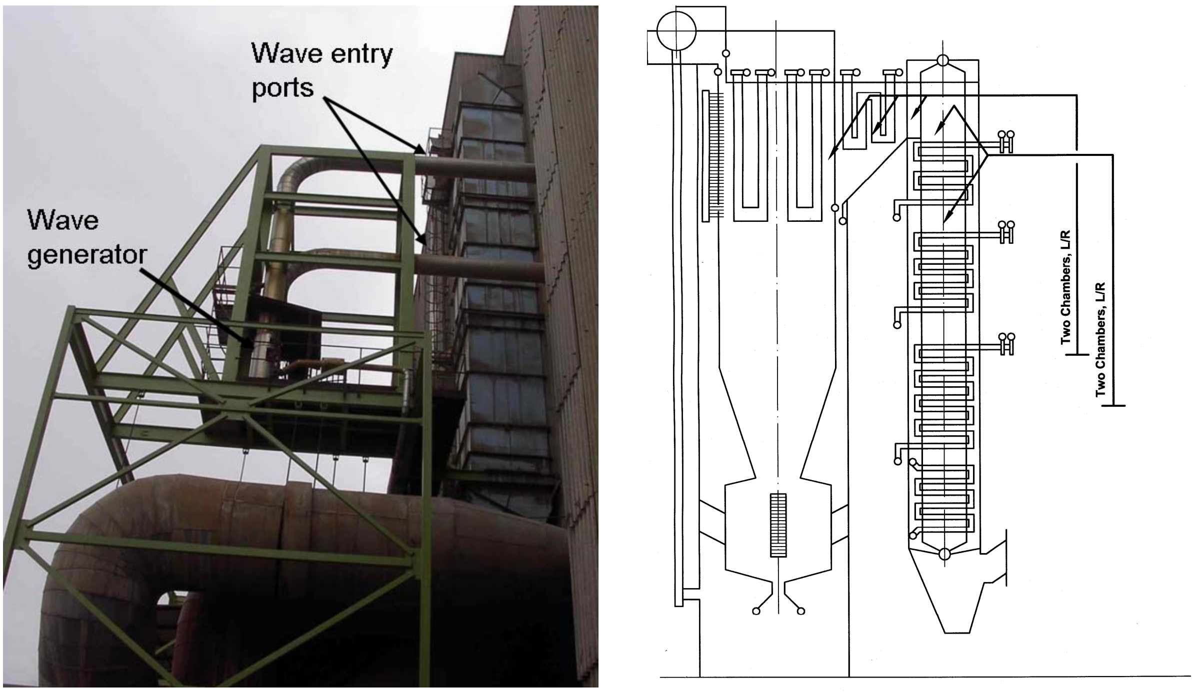
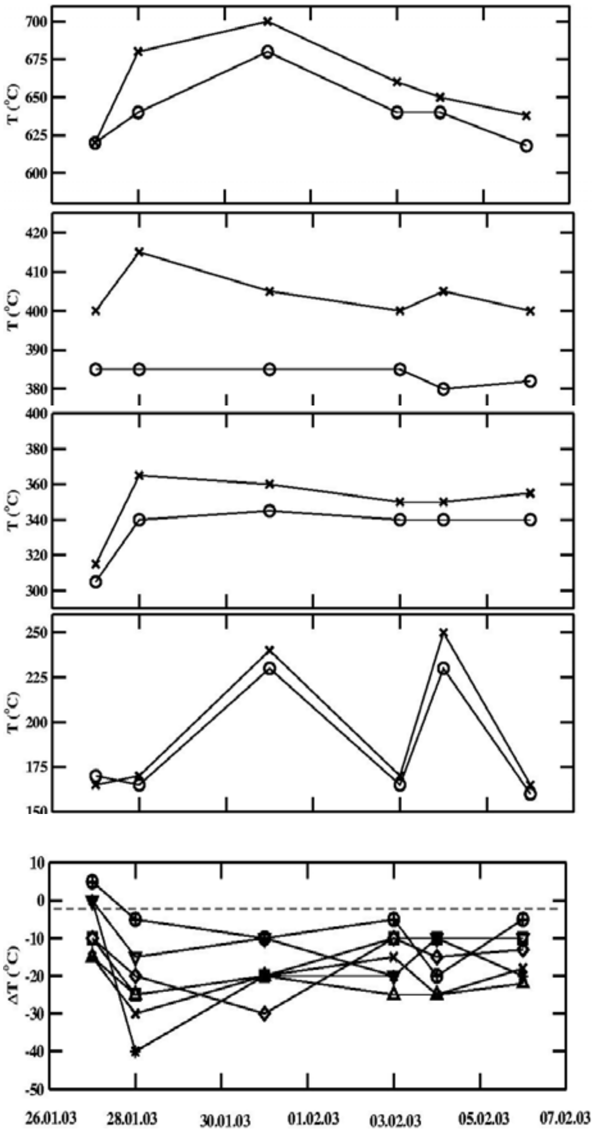


Fig. 4. Left: a view on one of the wave generators, lead pipes and entry ports. Right: schematics of Boiler I with piping system for lading waves into the boiles after reconstructions in 1996/97 and 2003.

On the occasion of the twentieth anniversary of continuous application of the detonation wave cleaning technique (DSB) a series of measurements were conducted in January-February 2003 similar to those done in 1983. Of course, boilers were now older, there were some other reconstructions and the coal quality and composition have probably changed slightly. Nevertheless, the observations and quantitative measurements appeared very similar proving no negative effects on boiler structures.

Figure 5 shows a typical recording over several days of the flue gas temperature in both tracts (left and right) performed recently in Boiler II at roughly the same locations as in 1983 and 1997. The results are very satisfactory with evident drop in temperature at all measuring stations. The effect is shown for a series of shots, typically 7 to 8 in one cleaning procedure, several times per day, depending on the boiler load, quality of coal and general performance indicators. A summary of the temperature drop for all measured locations is given in Fig. 5 bottom left. Very similar results are obtained for Boiler I (not shown here).



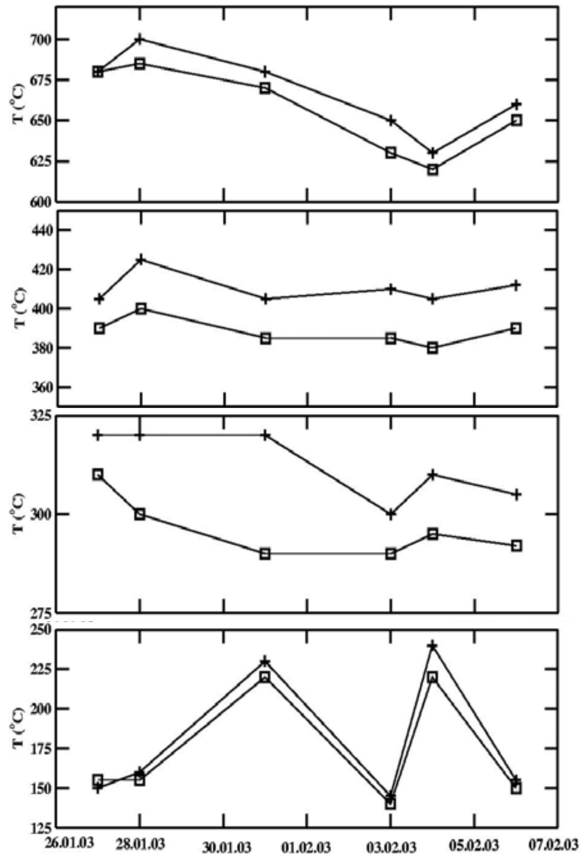


Fig. 5 Flue gas temperatures in two tracts of Boiler II at 75-85% load before (x left, + right) and after (○ left, □ right) using DSB. From above: behind superheater, in front and after economizer, and at boiler exit. Bottom left: temperature differences before and after using DSB for all locations. (January-February 2003) [4]

Conclusions

The three-decades of experience with detonation wave technique ("detonation soot blowers", DSB) for on-load cleaning of gas-side surfaces in two 340 t/h coal-fired boilers in the Thermal Power Plant Kakanj has provided sufficient information to fully judge and appreciate this unique technique. The method proved to be efficient, easy and inexpensive to install, easy to maintain, safe, reliable and very economical in exploitation. The cost of installation of the full equipment is comparable to those for installing 6–12 conventional, fixed steam soot blowers, whereas the exploitation costs are mush lower and amount only for the cost of fuel (here LPG), which in the case here described amounts typically to about 100 kg per week per boiler.

The method is based on the action of detonation waves generated in a special chamber ("wave generator") outside the boiler, which are brought into the furnace and gas passages through a pipe system. The detonation waves provide mechanical and thermal shocks on the agglomerated deposit breaking its interior bondage and making it sufficiently loose to be convected away by the flue gases. As compared with conventional fluid jet methods such as steam, air or water soot blowers, the impacting and reflecting waves provide more uniform and deep-reaching action, with no harmful effects. The wave entry ports can be installed on sidewalls or boiler ceiling at convenient locations, and oriented towards the tube packages or other critical areas exposed to heavy fouling and deposit agglomeration. The wave intensity can be adjusted according to the character and composition of ash. The best performance has been achieved by two to four daily cleaning routines consisting of a series of 6–10 relatively weak waves released every 30–60 seconds. The procedure can be made fully automatic, programmable according to a prescribed schedule, or to be activated whenever the monitored reference fouling parameter exceeds the prescribed value.

The technique has proven especially effective in removing the deposit while still relatively loose, prior to its hardening, and can thus be used as a prophylactic measure. It can be used to clean surfaces of all types of boilers and furnaces, though its best effects are in the convective tube packages. The technique can also be applied to other types of boilers and furnaces, fired with biomass, municipal or industrial waste, or to cleaning other equipment such as heat exchangers, reactors, industrial gas conduits and accompanying accessories: compressors, valves and fittings.

References

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