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CLEANING METHODS OF HEAT SURFACES IN BIOMASS-FIRED BOILERS: A REVIEW

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ABSTRACT

In biomass-fired boilers serious deposits are formed on heat-transfer surfaces which cause decrease in efficiency of energy production. Slags and fouling cause troubles in boiler operation even the blockade of the plant. In this paper various methods for elimination of slags and fouling from the heat surface are presented. An overview of the offline and online cleaning techniques of dirty surfaces is described. The main attention is directed toward soot blowing techniques, rapping devices, detonation-wave technique, sonic-wave cleaning and pneumoimpulsive method. Advantages and also disadvantages of methods are reported. It is concluded that is not a method which is universally suitable for cleaning surfaces for all types of biomass-fired boilers. Future investigation in problem is necessary.

KEYWORDS: biomass-fired, heat-transfer, detonation-wave, sonic-wave.

1. INTRODUCTION

Nowadays, there is a tendency to increase the efficiency and to low the cost of heating and electricity production. It requires finding cheap fuels, which will be treated in low cost boilers and devices which will work with high efficiency. Energy production by firing biomass seems to satisfy most of the mentioned requirements.[1] The origin of biomass is: agricultural residual and herbaceous material, wood or bark, animal and human waste, contaminated or industrial biomass.[2] The fuels like herbaceous materials,[3] straw,[4-5] corn,[6] cereals, roadside grass and wooden biomass,[7] agricultural residues,[8] crop residues,[9] are mixed with coal powder. During combustion of the solid biomass flues it is found that ash is built up and the un-burnt materials are conveyed in the flue gas.[10] The particles of material can settle on surfaces, accumulate under specific conditions and form a thick layer. The mechanism of deposition involves ash particle rebounding and sticking on the heat surfaces of boiler.[11] The condition for deposition is that the small fractions have high adhesion energy on the heat surface.

The quantity and quality of the fuel has an influence on ash generation. The higher the quality of the fuel and less the fuel need, the ash production is lower. Ash forms deposits on the exterior of the surfaces running through the boiler. Slagging and fouling alludes on deposition of ash on surfaces for heat transfer.

Slagging is termed as the deposition of fly ash on the heat radiation surface.[12] Fouling is constituted by gathering depositions in the heat recovery section surfaces.[13] It is found that the effect of slagging and fouling is characteristic not only for boilers fired with biomass but also for those fired with pure coal.[14-15] Deposit height depends on the type of boiler where biomass fuel is utilized[16-18] and on chemical properties of biomass. Namely, the deposition risk depends on the type of fired fuels. Serious fouling and slagging is created with the biomass fuel with high content of earth metals.[19] Li et al.[6] studied the mass, composition and morphology of the ash deposition during combustion of corn, wheat straw and saw dust. It is concluded that the deposit deeply depends on the sampling probe temperature and sampling time periods, too.

When burning agricultural residues,[8] that contain large amount of ash and impurities, problems with slagging occur. Thus, when firing herbaceous materials the ash deposition increases and the phenomena of corrosion of the metallic surfaces is evident. Comparing the tendency of deposition of ash particles of herbaceous biomass with that from lignite it is concluded that the deposits from the lignite are higher than for this biomass fuel.[15]

Investigation in deposit forming in mixed biomass fuel is also analyzed. So for example, experiments in the co-firing of coal-sunflower seed shells in power plant show that the deposit on the heating surface is formed in extremely short time.[16] Comparing fouling and slagging in firing with herbaceous biomass and wooden one it is seen that the first gives more deposit.[20]

Wang et al.[8] investigated formation of the ash deposit when coal is fired with agricultural residuals like peach and olive stones and wheat straw. It is obtained that the ash deposition is higher if coal with wheat straw and olive stones is fired than if the pure coal or peach stones are fired.[21] The formed deposits have high degree of adherence to the surfaces.

Ash-related problems are evident for raw materials other than pure stem wood. In[5] the ash deposit examination is done for co-firing wheat straw with two types of coals. It is concluded that combusting the straw the obtained deposit layer is heigher than for the case of pure coal. In[7] the fouling in boilers fired with fuel based on wood blends is investigated. There is no problem with wood pellets, but excessive fouling occurs if a mixture of deletion wood, compost, wood cuttings, roadside grass and paper sludge are fired. The fouling with wood chips, cutting blend and demolition wood is slightly higher than with wood papper sludge blend, compost cverflow and wood chips and cuttings.

The ash generated from the biomass combustion can lead to problems in thermal conversion process,[22] if the slag building up can be uncontrollable over time. Because of that it is important to predict biomass slagging and fouling. Unfortunately, coefficients determined for coal are not suitable to be applied for biomass and to predict the ash behavior as the biomass composition is significantly different from that of the coal.[23-25] In addition, in[12] it is concluded that there is not a unique and general formula available to correlate the slagging and fouling tendency of all biomass fuels. The real results would be only found on real combustion experiences in real systems. Further investigation is necessary.

Deposits on boiler tubes affect the operation and efficiency of a plant. Ash deposits formed during combustion and slagging on the surfaces and tubes of the boiler may reduce the heat transfer and the efficiency of the process. To reach the same temperature and produce the same amount of power as a clean boiler the dirty boiler needs more fuel.[26] Emissions produced by a power plant with increased fuel consumption are also increased.

Fouling in boilers can lead to over pressure in the boiler and also to damage by abrasion and erosion of boiler tubes and high-temperature corrosion. Ash deposits deteriorate burning, decrease the heat transfer, cause high temperature corrosion and may cause mechanical failures.[3,27,28] The corrosion under the slag can create a hole in the tube itself.

Finally, ash deposits may cause serious operational problems. Deposits may decreas or completely block the boiler operation by stopping the flow of the flue gas through the boiler and by blocking the chanels for flow gas. Then, the unscheduled boiler shut-down occurs which is very expensive.

These different technical obstacles need to be overcome or at least minimized[19] as it is required the long-time efficient operation of boilers. It is of great interest to protect the boiler of fouling and slagging and to remove the deposit from the heat transfer surfaces. In biomass combustion excessive fouling at a super-heater bundle can be attained after already a few weak of exploitation. Frequently deposit elimination extends boilers availability and operational time, maximizes thermal efficiency and reduces gas exit temperatures. The transfer between the working fluid and the flue gas is improved by elimination of the deposit layer. It is predicted that cleaning slag deposits inside a boiler can increase boiler efficiency between 1 percent and 4 percent.

2. Deposit elimination methods

To overcome the problem with slagging and deposits various techniques are developed. The simplest method is to lower the operating temperature of the boiler and to eliminate the potential damage to the heat exchange surfaces.[21] A method to prevent the boiler from slagging is to cycle the plant up and down. It is known that bringing the boiler down and back up to the maximal load can create some efficiency for the plant by partially removing the slag through cycling. From top to bottom boiler tubes would expand and the expansion and contraction of the tube would knock off slag. However, most of boilers are designed to be run at stable high loads, and to be cycled and to go from full load to half load, for example.

The authors of the paper[9] suggest solving the problem of deposits in boiler by designing new burner for ash-rich biomass materials. In[15] it is recommended to limit the application of some biomass in fuels which cause severe slagging and fouling inside the furnace and in the convective pass, or to improve the ash melting behavior[29] to minimize or even eliminate deposits accumulation.

However, fouling and slagging in biomass boilers exist and for prolonging the operation life of the boiler the shedding of deposits is necessary. The process of remove of deposit from a heat surface is called deposit shedding.[30]

Deposit shedding can be caused without any operational or mechanical influence, i.e., naturally or as a part of an operation in the boiler, i.e., artificially. Which type of deposit elimination is appropriate depends on the deposit characteristics.

Natural shedding in boilers is achieved by erosion, thermal shock and gravity shedding. Impacting hard fly ash particles the erosion of a sintered deposit occurs. If the gravity force causes a break inside the deposit it is said that the gravity shedding exists. The success of erosion and gravity shedding depends on the deposit strength, viscosity of ash and also melting properties.

Thermal shock shedding method is based on sudden change of temperature in the tube-deposit system. The flue temperature affects the temperature distribution in deposit. Due to the difference in thermal expansion coefficients cleaning of the heat surfaces occurs. It is worth to be mentioned that the thermal expansion coefficient, melting temperrture and strength of the deposit depend on its chemical composition.

Artificially shedding of deposit (usually named 'boiler cleaning') is arranged with mechanical and thermal shock devices. The ash deposits are removed by mechanical or thermal stresses. During the cleaning process a break inside the deposit occurs if the forcing effect on the deposit is larger than the deposit strength i.e., the inner force inside the deposit, or the adhesion force between the deposit and the tube. To produce the appropriate cleaning device it is necessary to know the values of adhesion force. Recently, some investigation on the adhesion between the deposit and tube in biomass-fired boilers are done.[29] It is found that the adhesion strength of biomass ash and of deposits depend on gas and steel surface temperature, deposit chemical composition, type of steel and on sintering properties (duration and temperature).

Cleaning methods are online and offline. Offline cleaning requires a planned outage, while online cleaning may occur during boiler operation. Many companies would prefer to use online cleaning solutions instead of offline cleaning of plants. However, if deposit buildup reaches a point where the online cleaning is unable to remove the slag, the plant must be taken offline for cleaning. Offline cleaning may involve water jets, compressed air or dynamite.

3. Offline cleaning techniques

Let us mention some of the oldest methods for offline cleaning of boiler tubes: firing slugs by using shotguns, striking of tubes with hammers to remove any build up at tubes, knocking off slag by using a large iron ball suspended on a chain or chisels, etc. All of methods were very dangerous and many people got hurt. Modern methods of offline boiler tube cleaning have made many improvements over older methods.

3.1. High-pressure water cleaning

The most often applied method for elimination of deposited materials is by continuous preventive washing with high-pressure water of boiler heating surfaces and also pipelines, bins, heat exchangers, ventilation systems etc. The method requires setting of pipes and enough water supplies. This conventional cleaning technique uses effects of direct impact of fluid on the surface. Then the washing away of deposits from the surface occurs.

3.2. Cleaning with dynamite

In regions where the water is deficit and the deposit on the tubes is significant, the use of dynamite as a method of offline cleaning is suggested. Heavy amount of slag sticks of dynamite are used. The primer cord is settled around tubes. The cord has connectors that delay the charges. Without using the connectors the process could destroy the wall or insulation of the boiler. The method with dynamite is dry cleaning without water. The destroyed slag falls into the hopper and down into the grinder and to sluice area. Dynamite can be used quickly and with less equipment. Using explosives to clean slag from boilers is not a new process, but it is one still in use that many operators prefer. The method is used for coal plants with hard deposit. It is suggested to be applied in biomass-fired boilers, too. The downtime for cleaning of the boiler is quite short.

Side effect of dynamite cleaning is the potential damage caused by vibration. In addition, it is important to avoid destroying the wall or insulation of the boiler.

3.3. Shot cleaning method

Shot cleaning represents one of the most widely applied cleaning methods. The shot cleaning uses small particles which move along the tubes and attack the slag. Particles have different geometries. Above the boiler a hopper for particles is installed. The shot is dropped down onto a distributor and the particles are redirected throughout the top of the boiler. Disadvantage of the method is that the shot cleaning may produce tube erosion.

4. Soot blowing technique

Soot blowing is a process where fluid with high pressure causes mechanical and thermal shocks which failure the deposit from heat surfaces in boilers. Soot blowers use high pressure water, stream or air which impacts the deposit, leads to its fracture and build up the slag. This method is very old one and arised in 1930s. Nowadays, most power plants have some sort of soot blower system that works to clean the plant during its power production.

Two types of soot blower systems are already utilized: the long distance and short distance system. Older soot blower systems applied the 'long distance' nozzle system for water spray across the boiler in order to reach the place that needed to be cleaned. That system used a large amount of water, which, after hitting the hot boiler tube, created the steam which caused disturbances and even a change in the power produced by the boiler.

The newer type of 'short distance' nozzle soot blowers, uses less water since over the shorter distance less cleaning force can be used. For this system the water reduction is 60 or 70 percent, but the efficiency of cleaning is better than for the previous system.

Sometimes for cleaning of boiler tubes very high pressure is necessary. Namely, soot blowers with supersonic steam jets knock deposits of tubes.[31] To remove the deposit, the peak impact pressure in soot blowing has to be increased above the deposit mechanical strength or the adhesive strength between the deposit and the tube. If the work of blower is not opportune the boiler area may foul quickly and cause a clinker.

In spite of its simplicity, soot blowing has many lacks. The major disadvantage of this cleaning method is that soot blower uses a significant amount of high pressure steam (3%-12%) which is generated by the boiler which otherwise would contribute to heat and electricity production. It is important to optimize soot blowing by minimizing steam consumption and maximizing deposit removal.[32]

Steam jets and air jets form traces on the heating surfaces and tubes indicating that the cleaning effects are localized to the areas which are directly swept by jets. Soot blowers are not able to clean the shaded areas behind the first rows of tubes. The accumulations in these blinded areas are difficult to clean if they form a structure. The problem can be diminished with soot lowers with telescoping tubing and controllable rotating heads that can penetrate deep into the tube packages. For individual cases the rotating blasting device is applicable. This technique is expensive and not suitable for all types of boilers.

Jet devices produce nonuniform cleaning which can lead to local damaging of tube surface due to strong abrasive and erosive jet effect of high-pressure steam.[29] Especially, there is a risk of tube damage and erosion if the soot blower is blowing high pressure steam on a bare tube. The systems could also interpret where the boiler is clean and the operator could avoid cleaning of sections of tube that are already clean. If water or steam hits a clean section of a boiler tube and if the water cleaning is improper, it can cause tube erosion over time or even damages of tubes if the hot tube is hit with cold water and the tube contracts. Steam and air jets form an additional unwished effect. Hard ash components, swept away by jets, give an abrasive action with the erosion as a consequence. In addition, some of undesirable effects of application of soot blowers are corrosion and bursting of boiler tubes. However, soot blowers reduce the furnace exit gas temperature[10] and slow down the deposition rate. The temperature decrease has a negative effect on the boiler operating parameters. Finally, it is important to mention that the installation cost of the device is significant.

The first soot blowing systems were quite simple without possibility for operator to have a feedback of cleaning without visual inspection of the boiler. In ’90 the improvement to the system is done by implementation of heat transfer sensors and of the automatic control system. The sensors of devices, placed within the cleaning radius of the water lances, provided feedback of heat transfer and were used to determine how clean or dirty was the section of the tube. Based on the obtained results the operator can make a decision where the system has to be placed which blowers make the biggest effect, and in the end how to form the boiler cleanliness with the less soot blowers. In addition, the operator can analyze the data from individual cleaning devices and to make cleaning as little as possible to avoid damages. If a soot blower installation is activated and the gas temperature on the furnace exit is negligibe, it can be concluded that either the surface is already clean or the deposit on the surface cannot be removed by soot blowing.[10] Nowadays, a specialized computer program is formed which is possible to determine types and necessary number of units, their optimal parameters but also the optimal configuration and dimensions of the cleaning surfaces. Romeo and Gareta[20] developed a control strategy with artificial intelligence (Neural Network and Fuzzy Logic Expert System) for optimizing the cleaning effect of the biomass boiler using soot blowing. In addition, maximizing of heat transfer along the time is obtained.

Intelligent soot blowing (ISB) activates the variation of pressure necessary for cleaning of boiler tubes. The system provides just enough (proper) pressure to clean the tube but to avoid creating any damage. However, the ISB is not able to answer the main questions: which is the adequate time for activation soot blowing in an industrial biomass boiler (one per shift, one each six hours,…) and which control strategy is the most convenient for optimizing cleaning process for maximizing heat transfer in time.

5. Cleaning techniques with pressure waves

For cleaning of deposits on heat surfaces pressure waves are applied. The waves, generated in boiler space or in a special device outside the boiler, propagate over the space, reflect from surfaces and clean them. Pressure waves propagate through the interior of boiler and produce distributed non local effects on all exposed surfaces without a direct fluid or solid impact upon them. Usually, pressure waves are generated in sonic horns and air cannons. These methods have not received a wider application in spite of promising advatages. Sonic horns generate fixed frequencies that can interact with the eigenfrequencies of the boiler structures. Air cannons are expensive and difficult to operate. For both it is difficult to focus waves on the critical areas of the heavily fouled surfaces.

5.1. Acoustic cleaning method

Sonic soot cleaning is a method applied to remove the ash and deposits on surfaces by using the sound energy.[33-34] Sonic waves force the flowing gas to move. Particles within the gas oscillate. The excitation of the acoustic wave creates particles to resonate and to dislodge particulate deposits. The motion loses the ash deposit and the system knocks ash of boiler tubes.

The method is superior over traditional soot cleaning techniques, such as steam blowers, for that the sound wave can propagate and the applied force can be altered. The low frequency sound wave can reach effectively to all parts of a boiler and propagate in a quite long distance with little attenuation. So, sound waves can eliminate the particle accumulation in blind spots which is impossible to be done with the most of cleaning methods. In addition, the method causes no erosion and damages on heat surfaces. The attractive aspects of the method include the low cost and easy installation.

In China one thousand sonic soot cleaners has been installed to hundreds of boilers. Several kinds of sound generators for sonic soot cleaning techniques are: sirens, Hartmann whistles and round panel whistles. The main specifications for sound wave generator are the sound radiation efficiency, power output and corresponding frequency: efficiency is around 10 procent, sound radiation power 146-152 dB, and the frequency 20 to 400 Hz. The higher the sound pressure level and the lower the corresponding frequency the more effective the cleaning is.

5.2. Detonation-wave cleaning method

Detonation wave cleaning technique is base on the application of shock waves produced by detonation of a fuel-oxidant mixture in a special chamber.[35] At the entry to the boiler The detonation wave is transformed into a shock wave at the entry of the boiler. The wave impacts the exposed surface and produces the breakage and removal of the deposit from the impact surface. At the end of the twentieth century Smajevic and Hanjalic[36-37] investigated the effects of the detonation wave technique on remove of the onload ash from te heat surfaces in steam boilers. Detonation waves are generated in an external wave generator. The detonation wave gives two effects: mechanical and thermal shocks.[38-40] First effect is that the wave excites the vibration of the tubes and boiler walls and it loosens the deposit. However, the main contribution gives the direct impact shock of the wave on deposit. In addition, the compressive and rarefractive waves in deposit cause losing the cohesive bonds in the material. Namely, the impacting compressive wave penetrates into deposit and reflects form the tube or wall surface as a compressive wave directed to the deposit free surface from which it reflects as a rarefractive wave. It is concluded that these rerafractive internal waves are major mechanisms for deposit destruction. The wave causes a thermal shock, too. It imposes thermal stress which weakens the adhesive force between the deposit and the tube surface. Existence of the thermal shock made the major difference between the detonation wave method and the previously mentioned air cannon method.

Comparing the method with the sound wave technique it is concluded that shock waves are more intense than sound waves (PowerPlus Cleaning Systems). The technique has all advantages of air cannons, but is much easier to operate and to control and is much less costly. In addition, the technique has advantages in boilers fired with solid biomass fuels or low-calorific trash, and fuels with high content of mineral constituents and ash. The technique is appropriate for cleaning molted fouling, too. The method is efficient as the detonation waves can be placed and directed towards the surfaces most prone to fouling.

Disadvantages of the detonation wave technique are connected with safety conditions and quality of air. Namely, after the shock impact the sudden dust flow occurs which causes a serious opacity excess. This problem is registered also in the case of sonic horns and air cannons.

5.3. Pulse and pneumoimpulsive cleaning techniques

Pulse-cleaning techniques use the effect of shock waves generated in special shock generators.[41] Thus, the pneumoimpulsive generator, which is the part of the pneumoimpulsive cleaning system, produces shock-wave impact of gas jets on ash deposits.[42] The pneumoimpulsive generator accumulates compressed air energy for a few tens of seconds after which the stored air is instantaneously (within a few fractions of second) discharged, producing a powerful impact on the boiler heating surfaces and performing the technological operation of cleaning inner surfaces. Thus, the impulse impact of air treats the surface.

Impulse cleaner has three separate pieces that ate bolted together into the field. One section is the combustion chamber fabricated from stainless steel. Next section is a casting which may be straight or curved. The third section is located inside the boiler of inside wall of the boiler. The fuel used by Impulse cleaner is ethylene gas which is non-liquefied composed gas. It is stored in containers and plumbed to a common manifold to supply cleaning systems. Fuel is supplied to each Impulse cleaner via piping and regulated down to the operating pressure of approximately 225 psi.

The impulsive wave is not erosive. It gives deep penetration throughout tube bundle. Intense cleaning waves approach tube surfaces, encompass tubes surfaces. However, the pneumoimpulsive cleaner is not available to clean molten deposits. Pulse cleaning devices are recommended for removal weakly fixed ash deposits. Devices are convenient for relatively small boilers where local cleaning of convective heating surfaces is necessary.[43]

6. Rapping device

Mechanism for cleaning with this device is based on rapping the polluted heating tube bundles causing an oscillation, which shakes the buildup material and removes deposits from the heating and reaction surfaces. Rapping is done mechanically on the strengthened back of horizontally arranged header. The beating energy causes the upright surfaces to vibrate and remove the dirt from them.

The impact is done by mechanical hammers or by pneumatically driven impact cylinders. For heavy fouling pneumatic rapping systems are recommended which can enable higher impact energies and as a result a still better cleaning effect.

For vibratory cleaning special structure for the heating surfaces is developed. Mechanical hammers beat on the rams causing the heating surface to vibrate. The boiler walls are provided with equispaced rams resting against the header bottom of the tube banks. All rams of a boiler side have to be equipped with this mechanical gear components and each ram has his own mechanical hammer. Rams need to be in-line. The impact energy applied by the mechanical hammer causes the vibration of vertical heating surfaces and the remove of deposits. The impact energy depends on the weight of the mechanical hammer and will be designed project-specific, for example 6-14 kg per each (Rosink Werkstatte). The existing combustion residuals fall off and can be removed through the hopper.

Rapping device system is suitable for cleaning horizontal superheater paths, especially for waste (incinerators plants), biomass and industrial plants. In the horizontal boilers support for the heating surfaces can be placed outside the flue gas. In addition, constuctions with heavy steel beams and stuctures available the support of large boilers. In the horizontal boiler the dirt obtained during cleaning process enters the hoppers and did not pass heating surfaces. Thus, the risk of blocking the tube system is reduced.

The advantage of the rapping method is that the impact energy necessary for rapping may be individually adjustable for the degree of fouling and optimized cleaning. In addition, individual rappers can be used for the zones which are difficult to be accessed. Installation costs are low. Visual inspection of ram is possible and the maintenance is simple. Optional the noise protection of the rapping system is necessary.

The cleaning is realized with a mechanical impact of solids. Thus, the deposit removal mechanism is based on the mechanical shock which effects on the breakup of the material deposited on tube packages and other boiler interior surfaces. Mechanical shock excites vibration of tubes and boiler walls which in turn loosens the deposited material. This effect depends on the tube size, tube dimension and wall configuration, amount and features of the deposited material, but also on the frequency and amplitude of the excited vibrations.

7. Tests of combined cleaning systems

Usually, in real plants the combination of the aforementioned cleaning methods is applied. In the literature, which is quite limited in number, effects of various cleaning procedures for deposit elimination in coal-firing boilers are presented.

Maidanik and Vasilev[43] investigated cleaning of slagging contamination of heating surfaces in boilers fired with lignite and bituminous coals. Tests are done with water and steam blasting systems. Several of working regimes are investigated. It was concluded that the boilers could not work long without different external cleaning of heating surfaces.

Mankina et al.[35] analyzed the influence of combined steam, water and oxygen cleaning of TPE-216 boilers installed at the Kharanorskaya SAPP in Russia. Unfortunately, it is found that the online cleaning did not give satisfactory results.

So, in the paper[44] the results of combined cleaning with steam slag blowers and water lances of the boilers firing Berezovo coal which produces intense slagging and fouling at the heat surfaces is presented. Experiments on the P-67 boiler were done in the period of 2006-2008. It is found that the parameter of boiler is decreased and the cleaning system was insufficiently effective: slag lamps grew near the burner and fell into cold funnel causing damage and produce strong deposits causing drop in thermal efficiency. Unfortunately, the combined cleaning method removed the problem only partially and the parameters of power unit and the maximal power output were decreased. Every year serious offline cleaning was necessary. In addition, the blowing steam pressure caused wear of tubes and surfaces. The steam blowing was twice a day. It was concluded that the steam blowing was not suitable to remove loosely coupled deposits growing on surfaces.

Vasilyev *et al*[45] tested the cleaning systems of P-67 boilers for the 800 MW units at the Berezovaskaya GRES (State regional electric power plant). It was concluded the combined steam and water blast systems did not eliminate the slagging on heating surfaces. To eliminate this disadvantage the maximal rated power had to be reduced for 100 MW and the hydrogen gas pulsed cleaning system had to be installed. It was found that the gas-pulse cleaning system was insufficiently effective for preventing the growing fouling on surfaces. Then, experimental devices for ultrasonic cleaning and vibration were installed, but did not yield the desirable results, too.

Agliulin *et al*[41] considered the pneumoimpulsive technology which has an impact effect on ash deposits with air jet, on PK-38 boiler at the Nazaravo district power station. In the boiler system the PG-25/6 pneumoimpulsive gas generator is installed. The test was done in the period of January 1, 2009 to October 1, 2009 without cleaning system, and five months from October 12, 2009 to March 1, 2010, with new pneumoimpulsive cleaning system. During the tests the flue gas temperatures downstream were measured by means of regular (state) thermocouples installed on two sides. It was shown that the cleaning efficiency of removing ash deposits from heating deposits from heating surfaces, especially for coals from the Kansk-Achinsk coal fields was not satisfactory. Additional cleaning of heat surfaces was necessary.

8. CONCLUSION

Recently, due to requirement for efficient energy production the productivity of plants and especially biomass-fired boilers has to be increased. Deposits formed on the heat surface of the boiler cause reduction of heat transfer and efficiency decrease. To overcome this lack and to improve the efficiency of boilers the variety of heat surface cleaning methods are developed. Which cleaning method is the most convenient depends on the fired-fuel properties and the design of the boiler. All of cleaning methods are not suitable for various fuels and various boiler constructions. Because of that choosing the right method for a boiler is up to the boiler designer and boiler operator. Namely, each boiler is a unique equipment and has own different problems which need to be solved individually. If the slag becomes the problem, it means that the installed cleaning devices are not enough strong or they are not in the proper location. Then, some innovation in cleaning system is necessary. Based on the new achievements in science and advances in techniques new cleaning methods have to be developed, which would be much simpler and safer for application. Innovations in this area of technique are welcome.

DECLARATION OF CONFLICTING INTEREST

The authors declare that there is no conflict of interest.

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