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BOILER SURFACE CLEANING FROM FRIABLE ASH DEPOSITS BY ACOUSTIC WAVES

Harri KÄÄR[a], Ülo RUDI[a], Andres SIIRDE[b], and Toomas TIIKMA[b]

[a] Energeetika Instituut (Institute of Energy Research), Paldiski mnt. 1, EE-0001 Tallinn, Eesti (Estonia)
[b] Tallinna Tehnikaülikooli Soojustehnika Instituut (Thermal Engineering Department, Tallinn Technical University), Kopli 116, EE-0017 Tallinn, Eesti (Estonia)

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Abstract. Applied on boiler surfaces, the acoustic cleaning method provides for ash deposits crushing and removal from boiler surfaces at low temperatures. Its efficiency depends on the properties of the sound field (i.e., frequency and sound level), the geometry (i.e., distance between the cleaned surface and sound generator and parameters of the tube banks), and mechanical properties of the deposits. Our tests were carried out under operating conditions in the laboratory and on the pilot equipment, consisting of a small heavy oil-fired boiler and an oil shale-fired steam boiler. Because the method was successful for friable deposit removal, intensive sound fields were recommended for multiple technological applications. To further extend applications and improve efficiency, new experiments are planned.

Key words: heat transfer surface, boiler, fouling, friable deposit, acoustic cleaning.

Fuel burning causes fouling of the heat transfer surfaces with ash deposits in the boiler units. Ash deposits decrease heat transfer. As dependent on their content, they contribute significantly to the corrosion of the boiler steel. When burning Estonian oil shale, the fouling and high temperature corrosion level of heat surfaces are highest. Neither can it be neglected at heavy fuel oil combustion, in particular, in the convective boiler tract. As local fuels (i.e., peat and wood) will be widely used in small boiler plants, the problem is becoming urgent.

To solve this problem, two approaches can be used. First, the combustion process is arranged and heat surfaces are designed so as to minimise the intensity of ash deposit formation. However, this does not remove the adverse impact on the boiler. The second approach provides various active methods for cleaning the heat transfer surfaces.

Cleaning of heat surfaces by steam or air blowing is most widespread. Large power engineering units also apply water blowers, gas pulsers, surface vibrators, and shot cleaners. A cleaning method is chosen depending on the rate and properties of deposit formation. To remove the thick deposits formed at a high temperature (i.e., on the screen heat surfaces and superheaters), a strong impact pulse is used. For this purpose, steam and water blowers appear relatively effective. However, they impose damaging thermal and mechanical impact on the metal heat surfaces. Another drawback is that sootblowers have a relatively limited cleaning radius. Thus, the number of units must be increased, and then such equipment is difficult to control. In convective tube banks, the tube cannot be flushed by a water or a steam jet throughout the whole perimeter. To clean friable deposits from convective heat surfaces, vibrators, shot cleaning or gas pulse devices are used. However, they have a mechanically damaging impact on heat surfaces and a non-uniform cleaning effect along the surface. The operational costs of the above methods differ significantly [1].

Due to the drawbacks described, a relatively new alternative – the acoustic method – is used in steam boilers to remove ash deposits from heat surfaces. For this method, low frequency acoustic waves (i.e., 16–25 Hz) at high sound level (i.e., 125–130 dB) can be used.

The acoustic cleaning method was first used in relatively low capacity steam boilers where steam blowers were replaced by sound generators, which achieved a higher cleaning and economic efficiency. As its application expanded, the shot cleaning units were replaced by sound generators to clean the electrodes of electrical filters and other components. This method was very valuable for removing friable and non-sintered deposits with relatively weak mechanical properties [2–5].

The tests conducted on our equipment under operating conditions showed that acoustic waves provide an efficient cleaning method. However, its theoretical foundations should be further developed. Our empirical data have been collected by the "test-and-error" method. Because the theoretical foundations are not well-established, this cleaning method is not widespread yet, and equipment malfunctions can occur [6, 7].

Low frequency acoustic waves are described as homogeneous: they spread equally in all directions, have low damping effect, and from larger surfaces (i.e., 95–98%) their sound field reflects extremely well. Based on these characteristics, we differentiate two steps in the analysis of the impact of the sound field: crushing of the deposits and removal of clinging and sticking solid particles, carried by the gas flow from the outer tube surface. For the latter, the acoustic cleaning will serve a preventive purpose: it hinders the sedimentation of solids on the surface and reduces its growth rate. Therefore acoustic cleaning can be regarded as a unique method, providing crushing and removal of deposits.

By flushing the tube banks with a gas flow, intensive vortices are formed behind the tube. Their location and frequency can be determined by the Strouhal number. In this region, an intensive formation of friable deposits can be observed. Presumably, under the impact of the sound field, the hydrodynamic configuration of tube flushing (i.e., development of the boundary layer, vortex formation and its parameters) will change.

The mechanics of deposit breaking has been mainly treated in the statical state, i.e., the crushing force induced on the deposit will not vary in time. When pressure waves are replaced by rarefaction waves (i.e., non-stationary or dynamic disruptive force), the forces of deposit breaking may be substantially smaller than those in the statical state if we assume porous friable deposits behave like a rheological medium.

To select the substantiated parameters of the cleaning equipment (i.e., sound pressure, frequency and scale of geometry), depending on the conditions (geometry of space and tube banks, properties of solid particles and deposits), the models of the acoustic cleaning method should be studied.

To develop an acoustic cleaning pilot equipment and test it in a steam boiler under operational conditions, a three-stage research programme was launched. This programme covers:

– test rig experiments to define the performance parameters of the sound generator and to investigate the impact of sound waves on the fouling dynamics of heat surfaces;
– determination of the interaction mechanism of sound waves and flows;
– pilot tests for cleaning heat surfaces in boilers by the acoustic cleaning method.

Next, we discuss our results. The impact of sound waves on heat surface fouling was investigated by flushing the checkered tube bank arranged in 15 rows with the air flow containing fly ash (i.e., average median diameter of ash particles was 30...40 × 10^{-6} m). The dust content remained constant at 0.1 g/m^3 throughout the experiment. The mass of deposits on the tube wall was measured at different flow velocities in the balanced state, where the deposit amount was constant in time. The test results were in good agreement with the published data. They indicated that the mass of friable deposits and their thermal resistance on the unit area depended on the flow velocity $m \sim Re^n$ where the index $n < 0$ (Fig. 1).

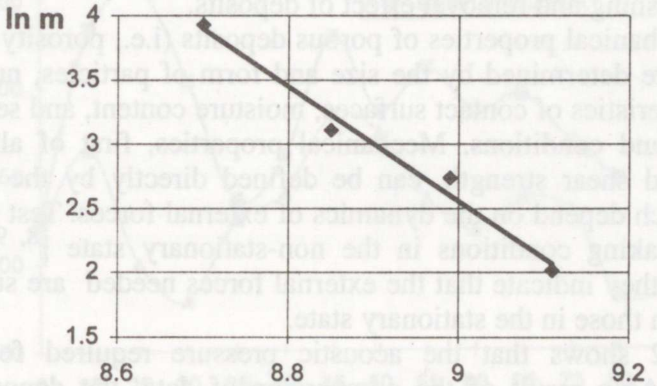

Fig. 1. The dependence of mass *m* deposited on the test tube from the Reynolds number.

As the velocity grew, the aerodynamical force imposed on the deposits increased, and thus their amount decreased due to the so-called self-cleaning effect. The self-cleaning effect depends on the mechanical properties of deposits and the value of n remained in the range of –6 to –1.

The following series of tests were carried out at various intensities of sound fields at the frequency of 60 Hz. The effective pressure of the fluctuating sound field ranged within 50–90 Pa (Fig. 2).

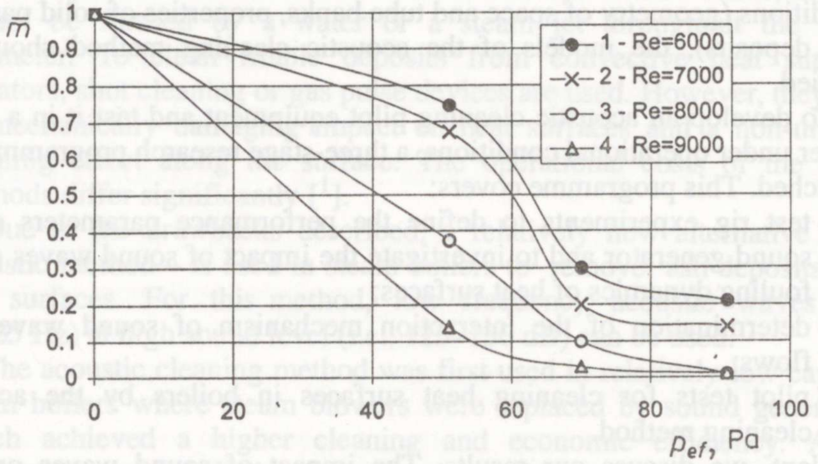

Fig. 2. The dependence of the relative deposit mass $\overline{m}$ ($\overline{m}$ has been found as a ratio of deposits formed in the sound field at the same flow velocity and under the condition without it) remanent on the test tube from the effective pressure p_{ef} of the sound field for different Reinolds numbers of the gas flow.

Our tests proved that deposits formed principally in the same way, i.e., the amount of deposits decreased with the growth of flow velocity, but the form of the relationship changed. To find the amount of deposits, we used the ratio of the deposit mass formed in the presence of the sound field to the deposit mass formed without the sound field present, for the same formation rate. Thus, the relative mass characterises only the sound field induced crushing and removal effect of deposits.

The mechanical properties of porous deposits (i.e., porosity may reach 70–80%) are determined by the size and form of particles, number, size and characteristics of contact surfaces, moisture content, and several other properties and conditions. Mechanical properties, first of all, breaking strength and shear strength, can be defined directly by the autohesion forces, which depend on the dynamics of external forces. Test data on the deposit breaking conditions in the non-stationary state [8, 9] are very scanty, but they indicate that the external forces needed are substantially smaller than those in the stationary state.

Figure 2 shows that the acoustic pressure required for breaking decreases. As a result of the comparison of data, the deposits can be described as friable.

We studied the interaction between the aerodynamical structures of the sound field and the tube by flushing to find the intensity and frequency of a sound field, where the resonance phenomena in the structure of Karman filament and a maximum cleaning effect could be obtained. The tests were carried out in an air channel of a quadrangular cross section (300 × 300 mm) with a cylinder of 40 mm diameter, installed in it. The low frequency sound waves were generated by a compressed air operated sonic generator. Measurements were made by a DISA hot wire anemometer and the corresponding probe set. To process the measured signals and determine the frequency parameters of vortices, two series connected computers were used. The output of the probe system was connected to an analogous digital converter, controlled by the corresponding software.

Though in the given sound field, at the frequencies of 10–50 Hz and the intensity of 118 dB, no uniformity of vortex ripping and changes in the turbulent structure of the boundary layer were found, regular structures in the boundary layer around the tube were sensitive to the sound waves.

The pilot tests of acoustic cleaning of heat transfer surfaces were carried out on the right air preheater of the convective tract in an oil shale-fired boiler and economiser of the boiler, operating on heavy fuel oil. To evaluate the efficiency of the acoustic cleaning method, employed in the oil shale-fired boiler, for cleaning the tube plate of the air preheater, the aerodynamic resistances of both tube banks in the air preheater were compared during a long term operation. To clean the left tube banks of the air preheater, only shot cleaning was used. Figure 3 illustrates the results of our experiment. The beginning of the time scale corresponded to the start-off of the acoustic cleaning system on the right side of the gas tract of the air preheater.

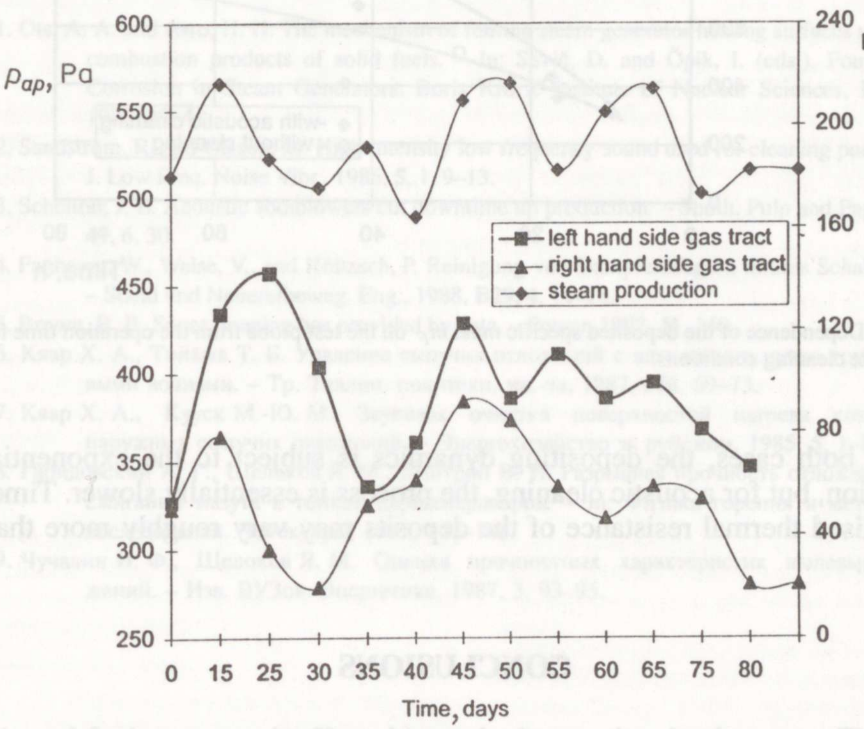

Fig. 3. Dependence of the aerodynamic pressure drop p_{ap} of the left and right gas tract of an air preheater and boiler steam production D (tons per hour) from the operation time.

The comparative tests showed that the aerodynamical resistance on the right gas tract of the air preheater was significantly lower than that on the left side. In addition, the tubes of the preheater functioned as additional resonators, amplifying the generated sound waves on the banks, distant from the generator. An increase in the contribution of the low frequency component was observed. Figure 3 shows the steam production of the boiler, which characterises the velocity of the combustion gases passing through the air preheater. Thus, we can explain the evident correlation between the aerodynamical resistance and the time dependence of steam production.

A special probe was designed for evaluating the efficiency of the acoustic cleaning method for cleaning the economiser of a heavy oil-fired boiler. This probe enabled us to measure the amount of deposited ashes on the probe relative to the boiler performance time. Because of significant fluctuations in the consumption of a pilot test boiler, its performance should be evaluated relative to the burnt fuel amount.

Figure 4 illustrates the comparative results of economiser fouling with and without acoustic cleaning.

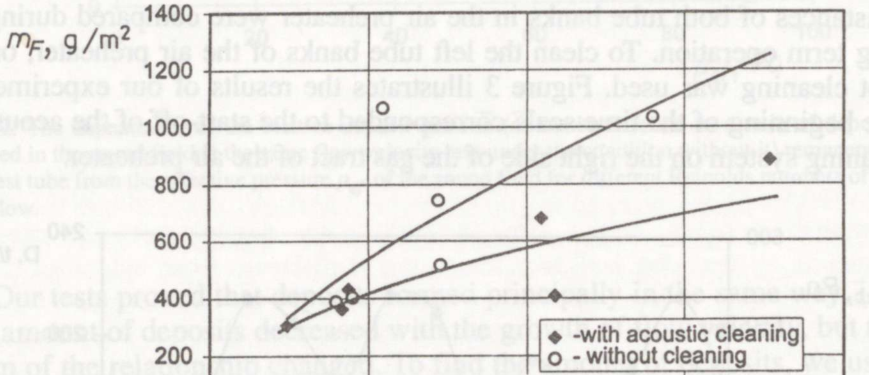

Fig. 4. Dependence of the deposited specific mass m_F on the test probe from the operation time for different cleaning conditions.

In both cases, the depositing dynamics is subject to the exponential function, but for acoustic cleaning, the process is essentially slower. Time-stabilised thermal resistance of the deposits may vary roughly more than twice.

CONCLUSIONS

1. The acoustic cleaning method provides effective removal of deposits only for limited conditions. These conditions include the intensity of the

generated sound, sound frequency, physical properties of deposits and the geometry. To achieve efficient operation, requirements for installing the cleaning equipment should be strictly followed.

2. Because of scanty data, the conditions affecting effective cleaning can be evaluated only qualitatively. To establish quantitative relations, the number of tests must be significantly increased. As a result, a physical model of the cleaning mechanism can be developed and the impact of the sound field on the speed of deposit formation can be explained.

3. Based on the results of the described tests, we can state that the method recommended is suitable in the heat generating units where friable deposits are formed. The acoustic cleaning method can be used on a wider scale, combined with other cleaning methods. For this purpose, the dynamics of deposit formation and the mechanical properties should be studied in greater detail to describe the joint action and operational regimes of various cleaning equipment. The preliminary data concerning the heat surfaces of steam boilers with fluidised bed furnaces indicate that the acoustic cleaning method is valuable.

4. The acoustic cleaning method can be applied in other technological processes, where friable deposits are formed, for example, in the food, pharmacological, and chemical industry.

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KATLA KÜTTEPINDADE PUHASTAMINE PUDEDATEST TUHASADESTISTEST HELILAINETEGA

Harri KÄÄR, Ülo RUDI, Andres SIIRDE, Toomas TIIKMA

Akustiline puhastusmeetod võimaldab purustada ja eemaldada tuhasadestisi katla madalatemperatuurilistelt pindadelt. Meetodi efektiivsus sõltub helivälja omadustest (sagedus, heli tase), geomeetriast (puhastatava pinna ja heligeneraatori vaheline kaugus, torupakettide iseloomulikud mõõtmed) ja sadestiste mehaanilistest omadustest. Katsetused tehti nii laboritingimustes kui ka masuudil töötavas väikekatlas ja energeetilises põlevkivikatlas. Kavas on uurida aerodünaamilise ja helivälja vastastikust mõju tuhasadestiste purustamisel.

ОЧИСТКА ПОВЕРХНОСТЕЙ НАГРЕВА КОТЛОВ ОТ СЫПУЧИХ ЗОЛОВЫХ ОТЛОЖЕНИЙ ЗВУКОВЫМИ ВОЛНАМИ

Харри КЯАР, Юло РУДИ, Андрес СИЙРДЕ, Тоомас ТИЙКМА

Акустическая очистка позволяет удалять золовые отложения с низкотемпературных поверхностей нагрева котлов. Эффективность очистки определяется параметрами звукового поля (частотой, уровнем звука), геометрическими характеристиками (расстоянием области очистки от звукогенератора, параметрами пакетов труб) и прочностными характеристиками отложений. Экспериментальные данные получены в лабораторных условиях, а также в условиях эксплутации малого мазутного котла и пылесланцевого энергетического котла. Эти данные представляют интерес для уточнения взаимодействия аэродинамических и звуковых полей в процессе разрушения слабосвязанных отложений.