Oil Shale, 2005, Vol. 22, No. 4 Special
pp. 475-485
ISSN 0208-189X

ANALYSIS OF EXPERIMENTAL RESULTS OF SONIC CLEANING SYSTEM IN OIL SHALE BOILER

V. BOROVIKOV*[(a)], J. KLEESMAA**[(b)], T. TIIKMA[(c)]

[(a)] Enprima Estivo Ltd.
8-303 Väike-Ameerika St., 10129 Tallinn, Estonia **
[(b)] Pentagra Ltd.
16B Kastani St., 10912 Tallinn, Estonia
[(c)] Department of Thermal Engineering
Tallinn University of Technology
116 Kopli St., 11217 Tallinn, Estonia

The technology of sonic cleaning underwent an extensive development during the last 10-15 years. That technology belongs to the cleaning methods of weak (soft) effect on the boiler construction. It prevents the formation of friable ash deposits. When using sonic cleaning, the sintering properties of ash deposits must be taken into account. The paper deals with some experience of using sonic cleaning system in oil shale-fired power plants of Estonia and explains some theoretical aspects of operating of the sonic cleaning system. The corresponding experiments and calculations were performed or supervised by Department of Thermal Engineering of TUT with co-operation of Narva Power Plants, Ahtme Power Plant, Pentagra Ltd. and Kockum Sonics AB (Sweden).

Introduction

As known, when a solid or heavy liquid fuel is combusted in boilers, the problem of fouling will arise due to the processes of mass transfer from flue gas flow which contains fly ash. The dependence of the structure, strength and thickness of ash deposits on grain composition of fly ash, and its chemical activity, temperature, velocity of flue gas, etc. is a complex function. Operating conditions determine melting properties of ash, its tendency to sintering and slagging. Sintering and slagging take place on surfaces and superheaters due to high temperature of flue gas (furnace) and surface (superheater). Friable deposits form on surfaces of economizer and air preheater and also in precipitators of different types.

* Corresponding author: e-mail *vitali.borovikov@enprima.com*
** E-mail *pentagra@datanet.ee*

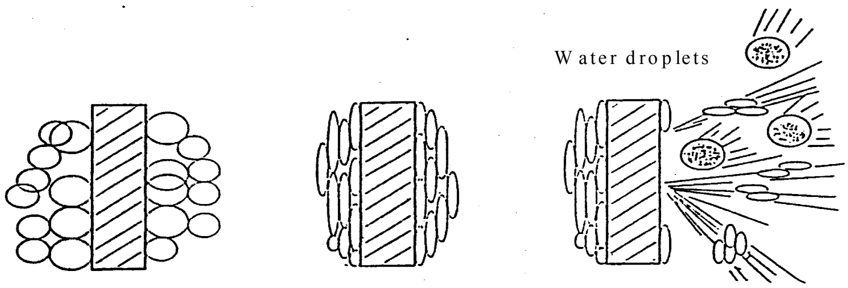
The intensity of fouling depends besides of above-mentioned factors also on time and aerodynamic conditions. It means that if we allow uncontrolled thickening of a deposit layer, its thermal resistance rises and due to that rising temperature of the outer surface of tubes makes sintering possible. That process starts avalanche action of closing the cross-section of gas duct [1, 7].

The choice of cleaning device and method must follow the conditions of deposition. Different temperature conditions and ash content demand the use of different technology. Also the frequency of switching in the cleaning process depends on the intensity of fouling. The history of design of solid fuel boilers knows a lot of methods for cleaning heating surfaces. The methods can be divided by their effective intensity on the surface as follows [2]:

- *Methods of hard effect* for cleaning from sintered deposits – water blowing – mainly in use to clean furnace surfaces with time interval 8–24 h. There are two types of water blowers: one device for each opposite wall which needs opening of a large size door in boiler wall (scanning system); the second one operates through a small hole and uses a long-distance device with 3–5 water nozzles of different orientation that are able to clean the whole furnace of a middle-size boiler. Water-jet cleaning can be recommended also for convective heat transfer surfaces, but the interval between cleaning cycles must be remarkably longer. Shot blast by iron droplets is historically well-known for cleaning convective surfaces.
- *Methods of medium effect* use mainly steam blowers, compressed-air blowers and vibration of tube banks, and water cleaning once in month at stoppages of the boiler.
- *Methods of soft effect* to the tube metal – sonic cleaning, pulse blowing (gas flash or explosion), etc. [3, 4]

The methods of hard effect are able to clean boiler surfaces completely, but their concurrent effect to the tube metal may challenge thermoshocks, erosion, etc., and due to that the period of their activation between cleaning cycles is quite long. The effects of operation of soft methods (as sonic cleaning) appear at their continuous operation – those methods can be considered preventive.

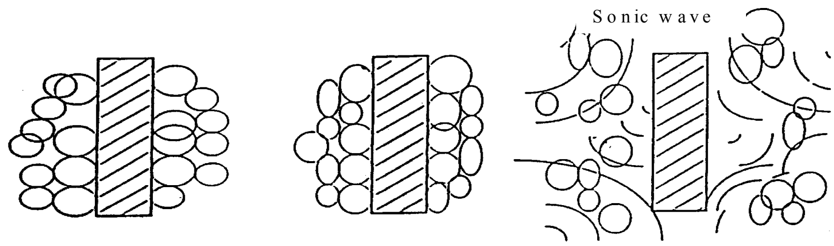
Figure 1 explains the effect of sonic cleaning. It consists of additional turbulization of gaseous medium which gives higher kinetic energy to the particles in the gas flow. Then oscillating particles are able to sweep friable deposits from the surface and, on the other hand, oscillating particles do not stay on the surface. Only sonic cleaning creates the possibilities for conveying mechanical energy from the source (sound generator) to the target without a direct hit by energy carrier. So, sonic cleaning has the preventive effect on the fouling process. This method is more effective if tube banks are covered only with friable deposits, and there are no possibilities of hardening by sulphation or recarbonation.



Soot particles will stick to the heating surface from the start of boiler

During one month the particles have enough time to form a thick layer of low conductivity

During the action of water cleaning only the particles reached by water droplets will be removed



After cleaning act sticking of soot particles begins

Short interval between cleaning cycles does not allow formation of a thick and sintered layer of deposits

As acoustic field, generated by sonic cleaner has a spherical structure, the particles will be removed from the whole surface

Fig. 1. Comparison of the effects of water washing of prolonged interval and short-period sonic cleaning

The Results of Sonic Cleaning Effect Research in TUT

First investigations on sonic cleaning at TUT were started in 1986 with constructing of the own version of low-frequency sonic generator for laboratory and industrial purposes. As first of all fouling and the maximal economical effect of cleaning are chracteristic of high-capacity power units of noticeable size, low-frequency sound as a more penetrable one was used. The sonic generator designed at TUT operated on the principle of rotating valve using compressed air pressure up to 0.5 MPa, the flow rate up to 0.1 m^3/s. That sonic generator operated at frequency of 22–24 Hz. The length of resonator tube was 4 m and intensity of the generated sound up to 136 dB. That device was used in several experiments at power plants [5].

Sonic Cleaning of Convective Part of Oil Shale Boiler TP-67

That boiler of nominal capacity of 100 MW_e uses one of the most complicated solid fuels in the world – oil shale –calorific value of fuel as received is approximately 8 MJ/kg, ash content about 50%. Due to high sulfur and CaO content of oil shale ash, ash deposits in the furnace are characterized by high strength and thickness. Because of complicated nature of fouling, several methods of cleaning of heating surfaces are in use at Estonian oil shale power plants.

For furnaces, as a rule, water blowing is used. For cleaning superheater screens a combined method of low-frequency balanced shaker (LFBS) is used. Water economizer is cleaned by shotblast after every 8 h. That system was designed as the main cleaning system for that surface. The main problems of exploitation of shotblast were the caking of shots after the non-continuous operation of the boiler, corrosion of shots and their loss. Shotblast wears heating surfaces. As the air preheater of that boiler is located directly above the economizer, shotblast affects the airheater, too.

Experiments at the Water Economizer of Oil Shale Boiler TP-67

The sound generator described above was mounted in the convective gas duct of TP-67 (as shown in Fig. 2) between the screen-shaped and tube-bank blocks of economizer (flue gas temperature between 370–430 °C). During first experiments the efficiency of sonic cleaning was studied by special calorimetric probe of fouling. The results of those measurements are presented in Fig. 3 as thermal efficiency of the probe *versus* exposition time of the probe. It is shown that the decrease in efficiency defined by (Eq. (1)) at continuous (1.5 h) operation of the sound generator is noticeably lower than that without sonic cleaning.

$$\psi = \frac{q}{q_0} \tag{1}$$

where q_0 – the heat absorbed by clean probe;
q – heat absorbed at actual moment during the test period.

It must be pointed out here that the probe for measuring cleaning efficiency was located at the distance of 15 m from the entering site of sound generator. So we can suppose that the penetration of the sound 22 Hz was satisfactory.

The results of industrial tests show that under functioning of the sound generator the relative thermal efficiency of heat transfer increases from 0.85 to 0.95.

During those tests an interesting comparison of the effects of different cleaning systems was done. It considered measurements of the emission of solid particles before the electric precipitator applying only one type of cleaning device. The results of those measurements are given in Table 1 and they show that by using only sonic cleaning the "generated" amount of dust was remarkable, but it was divided uniformly over the whole operation period. Due to that, there was no "volley"-emissions of friable dust as it is conventional by using the cleaning methods whose operating period is long (as cleaning by shotblast). Normal concentration of fly ash before the precipitator is about 40 g/m^3 [6].

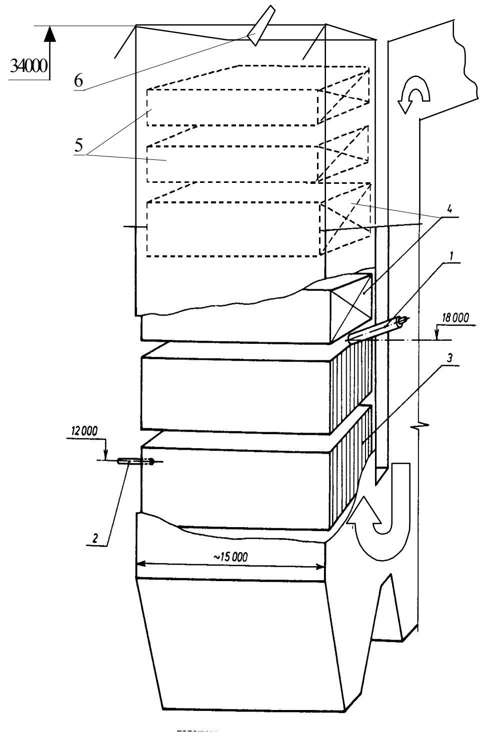


Fig. 2. Location of sonic generators and probe in oil shale boiler TP-67:
1 – sonic generator for cleaning of the economizer;
2 – location of the probe for estimating fouling intensity;
3 – screen-shaped water economizer;
4 – two tube-bundle economizers;
5 – air preheater;
6 – location of sonic generator on the air preheater

Table 1. **Comparison of the Effects of Different Cleaning Systems at Boiler TP-67**

Cleaning device	Duration of operation per day, min	The fly ash concentration, g/m^3	The amount of generated dust, kg/day	% of LFBS
LFBS*	120	39.3	43,710	100.0
Shotblast	30	90.0	28,985	66.0
Combined	3	37.8	1,217	2.8
Sonic	360	4.6	17,777	40.7

Notes: LFBS – system of balanced low-frequency vibration of superheater screens.
Combined – LFBS and Sonic.

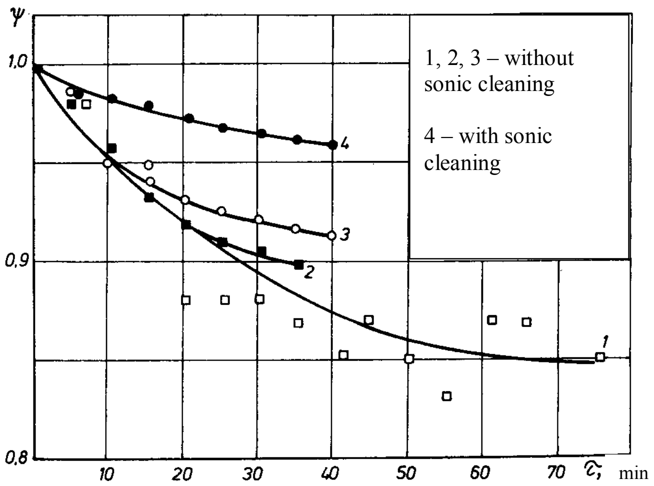


Fig. 3. Measurement results of fouling intensity in the economizer region of boiler TP-67

Sonic Cleaning of Air Preheater of Oil Shale Boiler TP-67

The sonic generator described above was mounted on the right side of the air preheater roof as shown in Fig. 2. That air preheater consists of three stages assembled from vertical tubes of diameter of 51/48 mm. The main problem of the exploitation of that air preheater is the fouling of tube flanges, which is accompanied by the growth of aerodynamic resistance of the gas duct. That experiment was started immediately after the complete cleaning of boiler and was held for ninety days. During that experiment the left branch was cleaned by shotblast and right branch only by sonic generator of 24 Hz. During the experiment the aerodynamic resistance of right and left gas duct of that boiler was compared. As boiler load was changed, the clearest presentation of the results can be achieved taking into account the situation at the start moment. As at the beginning of the experiment the resistance of both branches of the gas duct was the same (see Fig. 4*a*), that point can be taken as the reference point of boiler load and initial resistance.

The effect of sonic cleaning estimated as the ratio R of aerodynamic resistances of the right and left branches taking into account the changes in boiler load (see Fig. 4*b*):

$$R = \frac{\Delta p_R}{\Delta p_L} \frac{D_A}{D_0} \tag{2}$$

where Δp – the aerodynamic resistance of right (R) and left (L) branches of air preheater duct;

D_A – actual boiler load;

D_0 – boiler load at the start of the experiment.

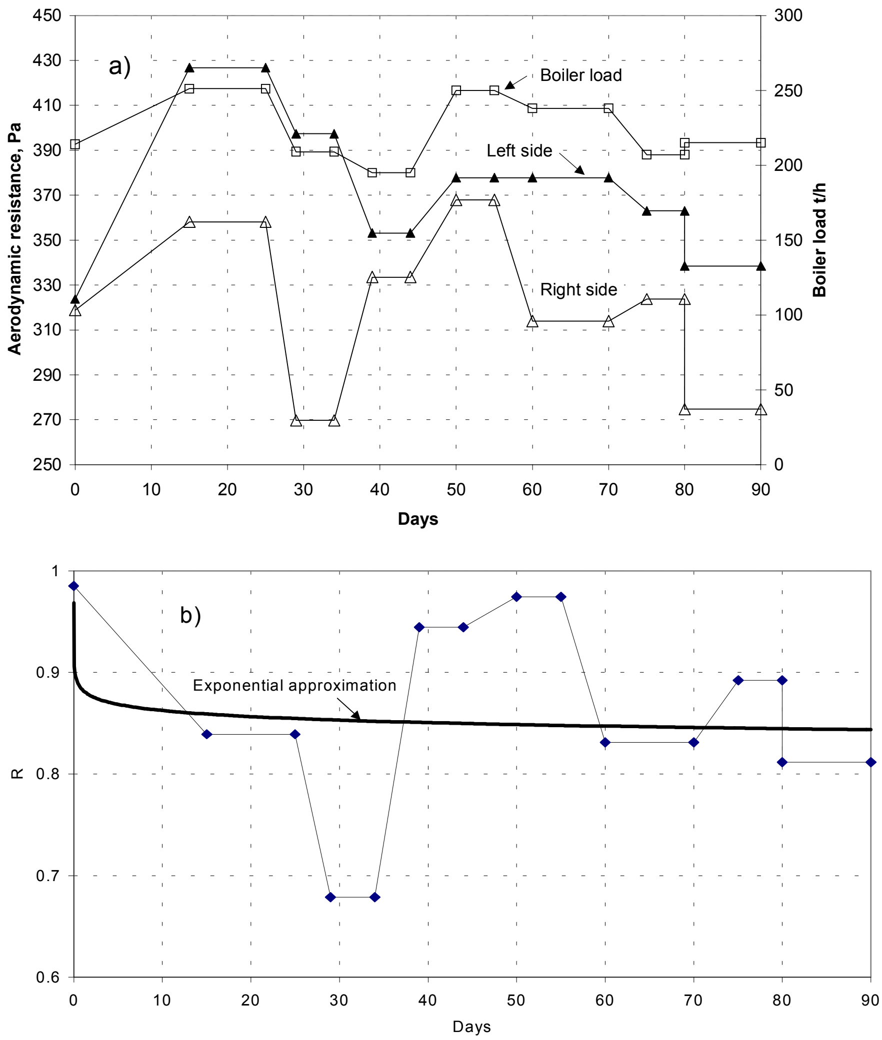


Fig. 4. Effect of sonic cleaning on the air preheater of boiler TP-67

Some Results of Superheater Cleaning by Infrasound Generator INSONEX 400 G of the 75 t/h Oil Shale Steam Boiler at Ahtme PP

The Ahtme Power Plant is located in North-East Estonia. This station produces hot water for district heating systems of the towns of Ahtme and Jõhvi and electric power.

The sonic cleaning system was installed at boiler No. 4 (*Buchau*) of Ahtme Power Plant in 2001. This is 75 t/h oil shale steam boiler for combustion of pulverized solid fuel. The design of the *Buchau* boiler is presented in Fig. 5.

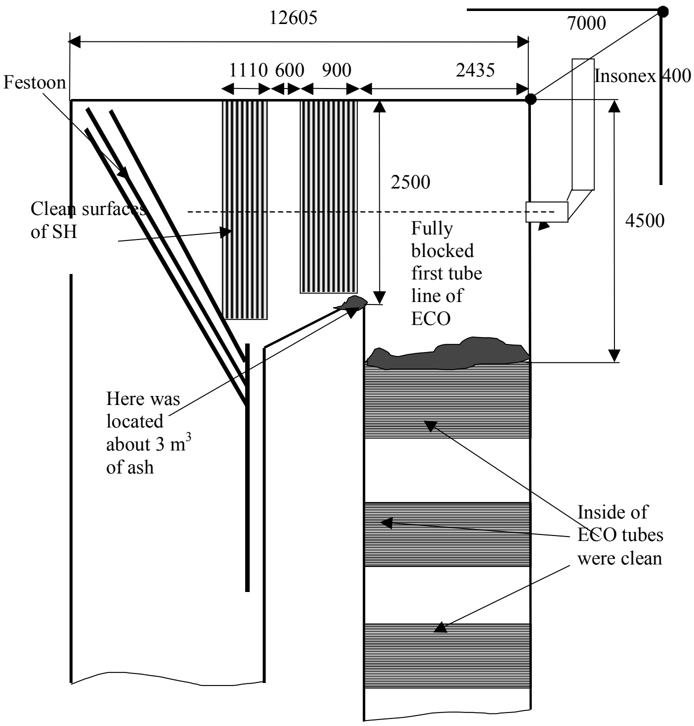


Fig. 5. Schematic view of 75 t/h oil shale steam boiler *Buchau*

Initially this boiler was designed for burning brown coal. As for cleaning and behavior of fly ash in convective gas duct, the design (performed in the 1940s) of that boiler is quite unsuccessful, because the material of ash deposit blown down from the superheater cannot be removed from flue gas duct, and it will form the deposits on the second stage of the superheater and economizer, as shown in Fig. 6.

Fig. 6. Conditon of boiler surfaces after 25 running days without sonic cleaning*:* a) superheater after 25 running days without sonic cleaning; b) economizer after 25 running days without sonic cleaning

Approximate concentration of fly ash in flue gas in the superheater region of that boiler is 60–90 g/Nm^3, and it depends on fuel quality and boiler load. For the solution of the listed problems the INSONEX 400 G (shown in Fig. 5) was installed. The superheater (SH) is cleaned by an infrasound sonic generator of 14.2 Hz with working conditions: 15 s working time, 2 min pause.

During introduction of sonic cleaning at that boiler superheater, five test series with duration of 15–25 days were performed.

The results of the first test after starting sonic cleaning are presented in Fig. 7 which present comparison of the dynamics of superheated steam temperature (as one of operation quality characteristics of power plant boiler) and the relative heat load of superheater during the reference period without sonic cleaning and with sonic cleaning. Figure 8 illustrates the condition of superheater and economizer surfaces.

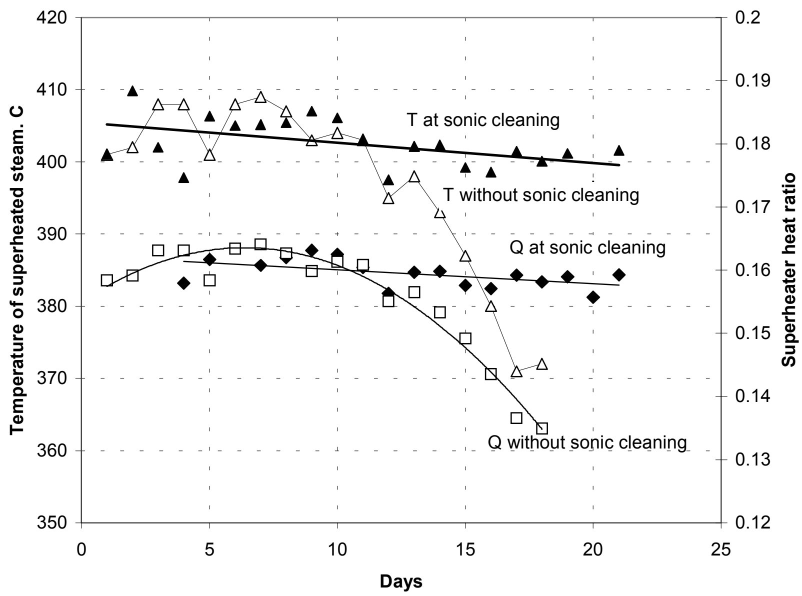


Fig. 7. Superheated steam temperature and relative heat load of superheater at comparison of sonic cleaning and the reference period without sonic cleaning

The data in Fig. 7 show that under conditions of sonic cleaning the steam temperature can be kept at the required level during 200–250 h. After that some active cleaning methods (for example vibration) must be used for short time for removing soft deposits from tubes. It is noted that after using of sonic cleaning the deposits at tubes become softer and more easily removable by vibration techniques. It shows that sonic cleaning can be used in combination with active cleaners of very rare operation (once per 1–2 weeks).

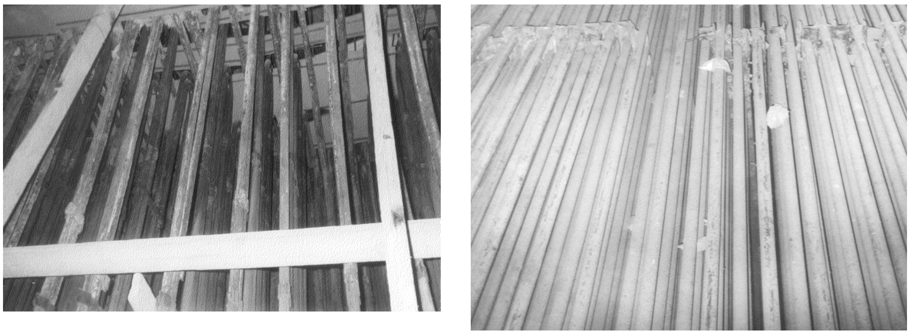


Fig. 8. Conditon of boiler surfaces after 25 running days with sonic cleaning: a) superheater after 25 running days with sonic cleaning; b) economizer after 25 running days with sonic cleaning

Conclusion

1. Investigations made at Tallinn University of Technology have shown that sonic cleaning allows keeping the required level of thermal efficiency of heating surfaces covered by friable ash deposits.
2. Infrasound generators of working frequency 14–17 Hz are recommended for cleaning boiler convective gas ducts whose cross-sections are over 4×4 m. Cleaning of boiler surfaces by low-frequency sonic field is a quite effective technology, if in the active zone of cleaning the intensity of the sound is over 140 dB. As a rule, different conditions in the boiler (size, fouling intensity and properties of deposits, temperature, etc.) need special tuning of the cleaning system and the choice of its operating frequency.
3. The technology of sonic cleaning improves the situation of fouling at high concentration of fly ash, but gives no absolute solution of that problem.
4. If there exist conditions favoring chemical reactions (sulphation, recalcination) and sintering of ash deposits sonic cleaning decelerates the formation of bound deposits. Experiments on monitoring of sonic cleaning show the possibility of such a phenomenon.

REFERENCES

1. *Ots, A., Zhelkovski, J.* Determination of fusion and sintering characteristics of ashes // Proc. 5th Intern. Conf. Heat Engines & Environmental Protection. 28–30 May 2001, Balatonfüred, Hungary.
2. *Tiikma, T.* Acoustic cleaning of boilers // Ecotechnology and Resource Saving. 2002. No. 1. P. 71–75 [in Russian].

3. *Käär, H., Kuusk, M*. Sonic cleaning of boiler's heating surfaces from friable external deposits // Power Economy Abroad. 1985. No. 5. P. 1–8 [in Russian].
4. *Shelton, J. L*. Acoustic sootblowers cut-down time. Up production // South Pulp and Paper. 1986. Vol. 6. P. 30.
5. *Käär, H., Tiikma, T*. Soot removal from staggered surfaces by sound waves // Transact. Tallinn Technical University. 1987. No. 656. P. 69–73 [in Russian].
6. *Jõgeva, J., Käär, H., Tiikma, T*. Industrial testing of sonic cleaning of economizer of boiler TP-67 from external friable deposits // Transactions of Tallinn Technical University. 1989. No. 692. P. 29–35 [in Russian].
7. *Borovikov, V., Kleesmaa, J., Tiikma, T*. Sonic cleaning of biofuel boilers // Proc. 1st Intern. Ukrainian Conference on Biomass for Energy. Kiev, 23–27, September, 2002.

Received 19 May 2005