JOURNAL OF ENVIRONMENTAL ENGINEERING AND LANDSCAPE MANAGEMENT
ISSN 1648–6897 print/ISSN 1822-4199 online
2012 Volume 20(4): 249–255
doi:10.3846/16486897.2012.695737

ECO-INTENSITY ANALYSIS FOR A CHIP-FUELLED BOILER HOUSE

Dagnija Blumberga[1], Edgars Vīgants[2], Ivars Veidenbergs[3], Ģirts Vīgants[4], Valdis Vītoliņš[5]
Riga Technical University, Institute of Energy Systems and Environment,
Kronvalda blvd. 1, LV-1010 Riga, Latvia
E-mail: [1]dagnija.blumberga@rtu.lv; [2]edgars.vigants@balteneko.lv (corresponding author);
[3]ivars.veidenbergs@rtu.lv; [4]girts.vigants@rtu.lv; [5]valdis.vitolins@rtu.lv

Submitted 28 Dec. 2011; accepted 17 May 2012

Abstract. The operational eco-intensity of a heat supply system is dependent upon the interaction of its elements and their common performance. It is of special importance to gain insight into possibilities to reduce chip fuel consumption in the case when an additional element − a gas condenser – is installed in a boiler house. The efficiency of a system's operation is estimated by its eco-intensity; such estimates concern the influence exerted by technological parameters on the reduction in natural resource consumption, allowing this problem to be thoroughly analysed by means of definite factors promoting the eco-intensity rise. Based on the results of commercial experiment, the authors have found the independent variables for the case of gas condenser without packing.

The eco-intensity of a boiler house operation decreases as the outdoor temperature falls and therefore the boiler's load should be increased. This aspect could be due to several causes, among which the most important are: the deviations of the operating parameters of the gas condenser, the increase in the flue gas velocity, and temperature. Analytical treatment of the influence exerted by a boiler's specific load on the operational efficiency of its energy has shown that as this former grows, the efficiency decreases and therefore less heat energy could be derived from the gas condenser. This should be taken into account at simulation of the control over a gas condenser's operation.

Keywords: Gas condenser, energy efficiency improvement, chip fuelled boiler house, heat supply system, optimization, eco-intensity, commercial experiments, environmental sustainability.

1. Introduction

In Latvia, the district heating systems (DHS) play a significant role, supplying about 80% of users with heat energy. This is economically cost effective from many points of view, as it is possible to achieve a higher efficiency of the energy production (Yin *et al.* 2008), at the same time taking into account heat losses in DHS. Another advantage of compact DHS is the possibility to use the wholesale trade principle, since all the expenses forming the tariff per MWh produced in a large system are comparatively lower. At the same time, socio-economic and ecological reasons should also be taken into consideration, since they could be associated with a rise in employment and reduction in import, as well as with the possibility to mitigate environmental pollution and the effect of greenhouse gas (GHG) emissions.

Currently, the Latvian energy sector faces a serious choice in its progress: to encourage all municipalities and local authorities to set short- and long-term goals of DHS development based on the bottom-up method.

The short-term goal is to secure the cheapest possible heat supply starting now. In fact, this would force to choose cheap and inefficient equipment, and, which occurs quite often, to make an unjustified decision as to the liquidation of a DHS.

The long-term goal: in the future, to secure a stable and the lowest possible price for heat energy that would be independent of the supply policy pursued by the supplier of imported fuel but dependent on the effectiveness of DHS operation. This would mean changing the current dominating governmental policy in the direction of sustainable heat supply.

The choice of technology currently and in the future is the one, which will determine energy sector development in the heat supply area to public and apartment houses (Difs *et al.* 2010). In this respect, at least four solutions exist:

- Residents and municipalities of rural areas and cities where the DHS has been destroyed are solving heating problem rather chaotically. Stoves are built in the rooms or boilers, with individual heating systems, are installed in the apartments. The flue gases are directed from apartments through a pipe which is installed on the wall external to the room. There are places where the end of such pipes falls below the roof level. The building walls are "pasted" with such smokestacks, their number sometimes equal to the number of apartments or rooms in the building. If there is a flat in a building, the inhabitants of which have gone abroad, the heating system falls into disrepair, since during the winter frost, the inside water freezes and then the ice thaws damaging the coatings and walls.
- Some municipalities have done and continue to do everything to maintain heating systems in buildings, and install boilers in the basement of

these buildings or nearby. The solution depends on the personal interest of inhabitants and the understanding of municipal officials regarding the future development of the territory. There are buildings where wood pellet, wood chips or firewood-fuelled boilers are installed, but, unfortunately, sometimes these are of low efficiency and consume large amounts of fuel.

– Some municipalities have chosen natural gas as the basic fuel. This undoubtedly is a comfortable fuel for the boiler houses of a DHS, however, imported natural gas is twice as much expensive than the local energy resources – wood chips, and thus the tariff of heat energy is higher compared to wood chips.
– There are also municipalities that purposefully make efforts to maintain energy-efficient wood chip fuelled furnaces in the DHS. Basically, these are municipalities that see the long-term perspective in energy sector development and try not to increase the heat prices for the energy users in their municipality.

Obviously, the last alternative is the best technological solution. The boiler houses that utilize power-generating wood are distinguished not only by the installed power and the built-in technological solutions, but also by their effective functioning (Neuenschwander *et al.* 1998). As shown by research in the field of flue gas condensers (Blumberga 1988), those are technical solutions for increasing energy efficiency of boiler installations. The use of wood fuel is important, because in this case the moisture content of flue gases is increased and therefore the recoverable potential of latent heat is high. The efficiency of gas condenser is determined by performance of boiler house and operation modes of heat network (Chen *et al.* 2012). It means that for the correct analysis should be seen heat supply system as a hole – source of heat, boiler house, gas condenser and heat network.

In the present paper, an analysis is conducted on the energy efficient chip-fuelled district heating boiler plant in Ludza town. The authors of this paper have provided the method to find optimal operating parameters considering the energy source as an element of the heat supply system.

2. The eco-intensity of the operation of a heat supply system

The operational eco-intensity of a heat-supply system is characterized by the possibility to raise the amount of heat energy that is produced at a boiler house, at the same time, not increasing fuel consumption. If the amount of heat energy supplied to the end users does not change, then the fuel consumption decreases (Che *et al*. 2004). The term eco-intensity in the existing literature is defined as “an indicator for the 'use of nature' (materials + energy + pollution) per unit of output” (EEA 1999). The eco-intensity emphasizes efficient use of nature resources, improvement of energy efficiency of DH system and reduction of air pollution in the case of use of gas condensing unit in wood chip fuelled boiler house. This would allow a reduction in natural resource consumption and hazardous emissions into the air, and the mitigation of the GHG effect. This creates and emphasizes a close connection which exists between solutions to environmental problems, and energy efficiency and eco-intensity.

The operational eco-intensity of a heat-supply system depends on the common energy-efficient performance of all its elements (energy source, heat network and energy user). The following technological, economic, environmental, and management aspects of the operation of a heat-supply system have an influence on eco-intensity:

– organisation of the combustion process in a boiler’s furnace;
– quality of the energy resource used;
– energy efficiency of the boiler unit;
– operating parameters of a DHS;
– professional management of a boiler house;
– parameters of cost effective equipment installation and functioning;
– rational utilization of natural resources;
– monitoring of hazardous emissions amount;
– control over GHG emissions.

The different elements of a heat-supply system are shown in Fig. 1, where the points for defining the operating parameters are illustrated. The system under consideration consists of the following elements:

– a boiler unit with technological tools for fuel and water preparation and purification, as well as for cleaning flue gases;
– a complementary innovative patented technology for a chip-fuelled boiler house: a gas condenser for deep cooling of flue gases, which consists of two series-connected parts;
– a heat exchanger for heating DHS water using the heat energy received in the gas condenser;
– a heat exchanger for heating DHS water using the heat energy received in the boiler;
– the DHS pipe system connecting the energy source with the end users of energy;
– consumers of heat energy which use it for heating buildings and hot water supply.

The operating parameters of a DHS are determined and estimated from the viewpoint of fuel consumption reduction. The aspect of environmental impact and climate change is also considered.

The gas condenser is structured in such a way that the processes occurring within the condenser complement each other, and the mass exchange conditions are optimal. In its first part, the cooling of flue gases occurs due to the evaporation of spraying liquid (Strotos *et al.* 2008), while in the second part, vapour condensation occurs on the surface of liquid drops (Miliauskas *et al.* 2010). Both these processes are equally important, balanced in order to create the largest possible amount of vapour, which could then condensate completely in the second part. The optimal operation of the condenser is dependent on its design and working conditions, on the efficient operation of the boiler equipment, and on the DHS operational parameters.

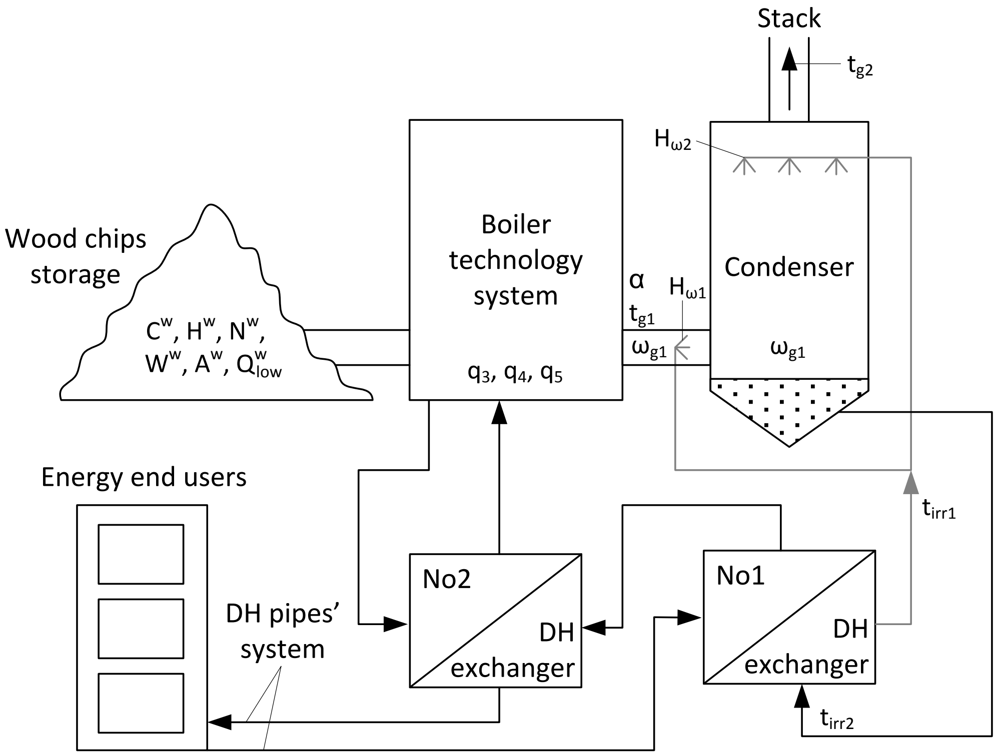

Fig. 1. Schematic diagram of the integrated DHS elements

2.1. A model for the estimation of DHS eco-intensity

The eco-intensity of a DHS in operation is determined by the interaction among its parameters. Mathematically, this is described by a system of equations that comprise a set of independent variables which are included in the model for the estimation of eco-intensity and make it possible to weigh different choices for optimizing the operation of the DHS.

In general, it is necessary to solve a set of four equations, the functional dependences of which are illustrated below. In this case, eco-intensity is characterized by a reduction in fuel consumption, i.e.:

$$\begin{cases} dB_1 = f(C^w, H^w, N^w, W^w, A^w, Q^w_{low}), \\ dB_2 = f\left(\alpha, t_{g1}, q_3, q_4, q_5\right), \\ dB_3 = f(t_{g1}, t_{g2}, t_{irr1}, t_{irr2}, \omega_g, H_{\omega 1}, H_{\omega 2}), \\ dB_4 = f\left(t_{ret}, t_{out}, G_{dh}\right), \end{cases} \quad (1)$$

where dB – reduction in fuel consumption; C^w, H^w, N^w, W^w, A^w – the composition of the applied fuel: carbon, hydrogen, oxygen, nitrogen, moisture and ash content, respectively; $Q_{low}{}^w$ – low heat value of the applied fuel; α – air consumption coefficient; q_3 – heat loss due to chemically incomplete combustion; q_4 – heat loss due to mechanically incomplete combustion; q_5 – heat loss in the environment; t_{g1} – temperature of flue gases before the gas condenser; t_{g2} – temperature of flue gases after the gas condenser; t_{irr1} – temperature of spraying liquid before the gas condenser; t_{irr2} – temperature of spraying liquid after the gas condenser; ω_g – velocity of flue gases in the gas condenser (can be different in parts 1 and 2, see Fig. 1); $H_{\omega 1}$ – density of spraying liquid in part 1 of the gas condenser; $H_{\omega 2}$ – density of spraying liquid in part 2 of the gas condenser; t_{ret} – temperature of water entering the DHS; t_{out}, – temperature of water exiting the DHS; G_{dh} – water flow in the DHS.

The reduction in fuel consumption is defined as:

$$dB = B_{BC} - B_B , \quad (2)$$

where B_{BC} – fuel consumption in a boiler house with a gas condenser; B_B – fuel consumption in a boiler house without a gas condenser.

The first equation in set (1) integrates the fuel quality parameters; the second one − the indices of DHS operation effectiveness; the third − the independent variables of a gas condenser's operation; and, finally, the fourth equation relates to the parameters of DHS control. In turn, heat loss through the flue gases is defined by the change in the parameters of these gases− the temperature after the boiler unit and the air consumption coefficient. Therefore, in the second equation (2) both parameters, which are assumed to be the input data for characterizing the gas condenser operation, are included: the flue gas temperatures, velocities, flows, and other characteristic factors of the eco-efficiency of the gas condenser (Val'dberg, Zhigun 2008a, 2008b).

The dependence in changes in fuel consumption on the quality of fuel can be calculated mathematically with the Mendeleev formula on determining the combustion heat of the fuel. This can be done if one assumes that the heat volume Q_{prod}, which needs to be produced, is constant. This assumption also applies to the constant values η of the rate of efficiency.

In this case, it is possible to calculate the reduction in fuel consumption with an adapted equation of the direct heat balance:

$$\Delta B_1 = \frac{Q_{prod}}{\eta \cdot \left(\frac{1}{Q_1^W} - \frac{1}{Q_2^W} \right)}, \quad (3)$$

where η – rate of efficiency of the boiler; Q_{prod} – amount of heat produced; Q_1^w, Q_2^w –combustion heat – initial and final, respectively.

In respect to wood chips, it is assumed that the initial combustion heat conforms to low quality wood with high moisture content and a high proportion of ash. The final combustion heat which is regulated by the EU standard to energy wood, on the other hand, is considered as, for instance no larger than 25% for moisture content of wood chips.

By mathematically adapting this formula it is possible to achieve the following formula:

$$\Delta B_1 = \frac{k_1}{Q_{low_2}^W \cdot \left(\frac{Q_{low_2}^W}{Q_{low_1}^W} - 1 \right)}, \quad (4)$$

where $k_1 = Q_{prod}/\eta$ – primary indicator of energy use.

The low heat value of the fuel is dependent on the content of the fuel and mathematically this can be describes as follows:

$$Q_{low_i}^W = k_C \cdot C_i^W + k_H \cdot H_i^W - k_{OS} \cdot (O_i^W + S_i^W) - k_W \cdot W_i^W, \quad (5)$$

where k_C = 339 – carbon ratio; k_H = 1031 – hydrogen ratio; k_{OS} = 109 – ratio between oxygen and sulphur; k_W = 25 – moisture ratio.

The values of the components C^w_i, H^w_i, O^w_i, S^w_i, W^w_i which are present in the fuel are given as percentages.

The higher the moisture content in the wood chips, the larger a reduction in fuel consumption it is possible to achieve, if the moisture content can be minimized to the standard value.

The equation (4) defines the costs of the fuel consumption depending on the efficiency of the combustion process, the parameters of the cooling of the flue gases and other values typical for the efficiency ratio of the boiler. This applies if the previously stated assumption is considered, that the volume of heat which it is necessary to produce Q_{prod}, remains constant. This assumption differs because it applies to the low heat value, which in this case remains constant.

In this case it is also possible to calculate a reduction in the fuel consumption by applying an adapted direct heat balance formula, which will differ in that the formula's variable is the indicator of the boiler's energy efficiency – the efficiency rate:

$$\Delta B_2 = \frac{Q_{prod}}{Q_{low}^W \cdot \left(\frac{1}{\eta_1} - \frac{1}{\eta_2} \right)} = \frac{k_2}{\eta_1 \cdot \left(1 - \frac{\eta_1}{\eta_2} \right)}, \quad (6)$$

where η_1, η_2 – boiler efficiency rate at the start and end of the technological process, respectively; $k_2 = Q_{prod}/Q^w_{low}$ – rate of application of the primary energy source.

During the wood chip combustion process, it is possible to organise the process in the furnace and cooling in order to reach an efficiency rate of 85% – 88%, a rate which can be considered as energy efficient, well-organised technological process which conforms to the standard values regulated in different EU member countries. The consumption heat of the starting efficiency rate of the boiler can be considered for low quality wood with a high moisture and ash content.

The efficiency rate of the boiler is determined with the adverse heat balance equation:

$$\eta_i = 100 - (q_{2i} + q_{3i} + q_{4i} + q_{5i}), \quad (7)$$

where q_{2i} – heat loss through emitted flue gases.

Heat loss through escaped flue gases is primarily dependent on the rate of air use and on the enthalpy of the flue gases which are determined on the equation:

$$q_{2i} = 1 \div \{ Q_{low}^W \cdot [(c'_{CO_2} \cdot V_{CO_{2i}} + c'_{N_2} \cdot V_{N_{2i}}^0 + c'_{H_2O} \cdot V_{H_2O_i}^0 + (\alpha - 1) \cdot c'_{air} \cdot V_i^0) \cdot t_{g1_i} - \alpha \cdot c'_{air} \cdot V_i^0 \cdot t_{air_i}] \cdot (100 - q_{4_i}) \}, \quad (8)$$

where c'_{CO2}, c'_{N2}, c'_{H2O}, c'_{air} – gas and air specific heat capacity; V^0_{N2i}, V^0_{H2Oi}, V^0_i – volume of nitrogen, steam and air as component of the gas which are created as a result of the stoichiometric combustion; V_{CO2i} – volume of three-atom gases; t_{g1i} – temperature of the flue gases after the boiler; t_{air} – supplied air temperature in the combustion process.

By expressing air and gas volumes in the equation (8) from content of fuel, it is possible to determine heat loss through emitted flue gases using equation:

$$q_2 = \frac{1}{Q_{low}^W} \cdot \Big\{ \Big\{ \Big[K_{1C} \cdot c'_{CO_2} + K_{2C} \cdot c'_{N_2} + K_{3C} \cdot c'_{H_2O} + K_{4C} \cdot (\alpha - 1) \cdot c'_{air} \Big] \cdot c_i^W + \Big[K_{1H} \cdot c'_{N_2} + K_{2H} \cdot c'_{H_2O} + K_{3H} \cdot (\alpha - 1) \cdot c'_{air} \Big] \cdot H_i^W + \Big[K_{1S} \cdot c'_{CO_2} + K_{2S} \cdot c'_{N_2} + K_{3S} \cdot c'_{H_2O} + K_{4S} \cdot (\alpha - 1) \cdot c'_{air} \Big] \cdot S_i^W + K_{1N_2} \cdot c'_{N_2} \cdot N_i^W + K_{1W} \cdot c'_{H_2O} \cdot W^W - \Big[K_{2S} \cdot c'_{N_2} + K_{3S} \cdot c'_{H_2O} + K_{4S} \cdot (\alpha - 1) \cdot c'_{air} \Big] \cdot O_i^W \Big\} \cdot t_{g1_i} - \Big(K_{4C} \cdot \alpha \cdot c'_{air} \cdot c_i^W + K_{3H} \cdot \alpha \cdot c'_{air} \cdot H_i^W + K_{4S} \cdot \alpha \cdot c'_{air} \cdot S_i^W - K_{3O} \cdot \alpha \cdot c'_{air} \cdot O_i^W \Big) \cdot t_{air} \Big\} (100 - q_{4_i}), \quad \% \quad (9)$$

where K_{1C} = 0.0187; K_{2C} = 0.07; K_{3C} = 0.00143; K_{4C} = 0.089 – carbon ratios; K_{1H} = 0.21; K_{2H} = 0.11528; K_{3H} = 0.266 – hydrogen ratios; K_{1S} = 0.007; K_{2S} = 0.026; K_{3S} = 0.00053; K_{4S} = 0.033 – sulphur ratios; K_{1N} = 0.008 – nitrogen ratio; K_{1W} = 0.0124 – moisture ratio.

Gas and air specific heat capacities in the equation (9) have to be assumed according to the temperatures t_{g1} or t_{air}.

The equation (5) describes the reduction in the consumption of the primary energy resource, by applying a gas condensing unit, the steam of which are condensate by the flow of flue gases (Cortina 2006). In this case, mathematically several processes are described: cooling, vaporization and condensation that occurs both separately and simultaneously in the gas condenser. Due to the complexity of the mathematics of these processes, an experimental data processing of the gas condenser was conducted and empirical coherence to the processes mathematical descriptions were acquired (see sections below).

The equation (6) that mathematically describes the reduction of primary energy use is associated with the assumption that the fuel's consumption heat Q^{w}_{low} and the produced heat volume Q_{prod} remain constant.

An important role in this case is that of the values of the parameters in the produced heat energy balance in the equation:

$$Q_{prod} = c_{wat} \cdot G_{dh} \cdot (t_{out} - t_{ret}), \quad (10)$$

where c_{wat} – specific heat capacity of water.

The interrelation between parameters indicates that the return water temperature of the heating network has an effect on the fuel consumption: the lower the return water temperature, the higher the economy on fuel consumption. This is associated with the temperature of the released gases and thus also to the efficiency rate.

2.2. A model for investigation of the boiler house operation

The installation and operation of an economical, cost effective boiler house unit is associated with the necessity to reduce its operational cost in order to raise the efficiency of its functioning. For example, the installation of equipment for deep cooling at a boiler house requires capital investments that could be paid back in 3–10 years, depending on the installed capacity and chosen type of equipment.

In Ludza town boiler house, a gas condenser that serves as an experimental polygon for scientists is installed to not only investigate heat-and-mass exchange processes, but also to determine the operational efficiency of such equipment. The condenser is designed in such a way that it is possible to operate it: with and without packing, with spraying nozzles that can be switched on or off in different places, and with variable spraying densities.

The eco-intensity of a boiler house's operation is defined dividing the total heat produced at the boiler house in a unit time by the heat produced by the boiler in the same time period:

$$\Delta q = \frac{(Q_{gc} + Q_b)}{Q_b}, \quad (11)$$

where Q_{gc} – heat produced by the gas condenser, MWh; Q_b – heat produced by the boiler, MWh.

The changes in the operational eco-intensity of a boiler house demonstrate the possibility to raise its heat energy production, without increasing fuel consumption.

The specific load of a boiler is determined by the ratio between its actual and installed capacities:

$$q = \frac{Q_{act}}{Q_{inst}}, \quad (12)$$

where Q_{act} – actual capacity of the boiler, MW; Q_{inst} – installed capacity of the boiler, MW.

3. Results of commercial experiments on the operation of the boiler house

Series of experiments involving determination of condenser operational intensity without packing are illustrated in Figs. 2 and 3.

The data obtained in the commercial experiment include the operational parameters of the boiler house which depend on the consumed heat load determined both by the consumer's behaviour and by the climate conditions along with the conditions of DHS functioning.

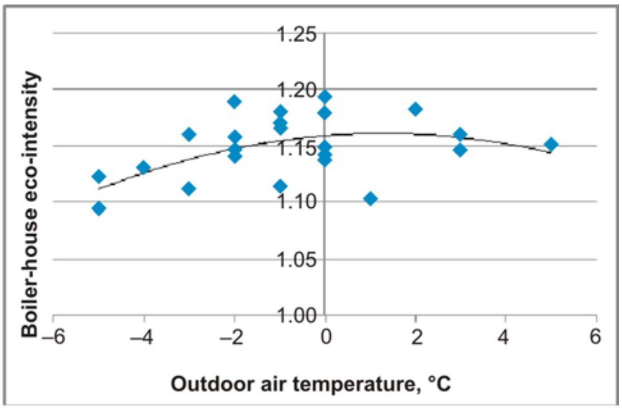

Fig. 2. Eco-intensity of a boiler house's operation *vs.* the outdoor air temperature

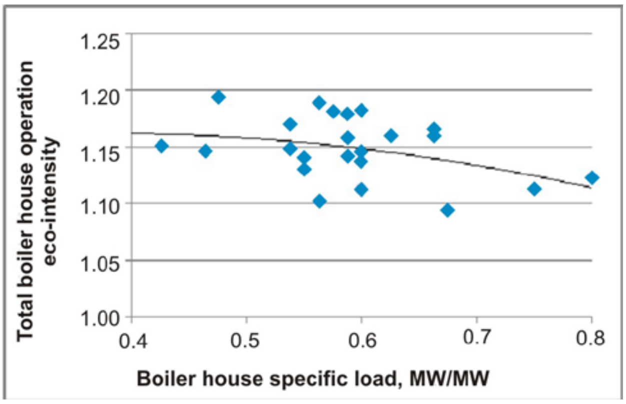

Fig. 3. The eco-intensity of a boiler house operation *vs.* the specific load

As could be seen from Fig. 2, the eco-intensity of a boiler house's operation decreases when the outdoor air temperature falls. This can be due to several causes, from which the deviations of the gas condenser without packing parameters − the flue gas velocity and rising temperature − from the optimum are the most influential.

This statement is confirmed by the analysis of another parameter that exerts influence on a boiler house's operation: its specific load. The analysis provides evidence that the greater the load, the lower the eco-intensity of the boiler house's operation and the smaller the amount of heat energy can be derived from the gas condenser (see Fig. 3).

The above confirms the mentioned hypothesis that at the time when the air temperature is falling, the boiler house's load and, therefore, the fuel consumption increase, which means greater volumes of flue gases.

4. The operation of a DHS

The operation of any DHS is determined by a complex set of technological solutions related to each individual element. Such a set should be considered as an integrated system, the effective operation of which would be dependent on the creation of economically-substantiated and environment-friendly technological solutions.

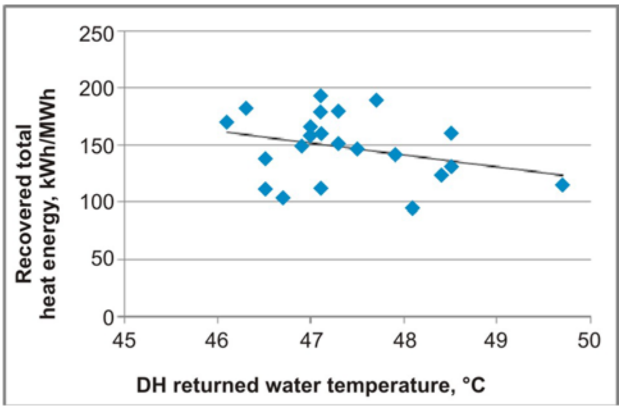

Fig. 4. The gas condenser recovered heat energy *vs.* the DHS returned water temperature

As seen in Fig. 4 (evidenced by the regression analysis), the experimental data poorly correlate with a straight line in the empirical model. Nonetheless, one trend is clearly evident: the specific heat derived from the condenser is greater if the returned water temperature of the DHS is lower and vice versa, the amount of specific heat decreases as the temperature rises.

All this confirms the above mentioned viewpoint that fuel saving depends on the operation of a DHS (with one of the elements being a gas condenser) as a whole. In turn, the operation of a gas condenser depends on the energy efficiency of the connected DHS users, as well as on the water velocities and flows in all the elements of a heat network including the heat exchangers at the heat substations of the buildings. In order to raise the amount of heat derived from a gas condenser, it is necessary to reduce the DHS returned water temperature. This could be done by modelling − qualitatively and quantitatively − the operating conditions and control of the heat-supply system.

Increase in the eco-intensity of a boiler house with a gas condenser should also be estimated from the viewpoint of the reduction in nitrogen oxide emissions, which is achieved in two ways:

– less fuel is consumed, therefore the total amount of nitrogen oxide emissions from the boiler house's stack decreases;
– some components of the nitrogen oxides are partially absorbed by the spraying liquid: 10% of the total NO_x amount is caught by this liquid.

5. Conclusions

1. The operation of a chip-fuelled boiler house with installed gas condenser depends on the functioning of the heat-supply system as a whole. The estimation of such a system's operational efficiency based on the eco-intensity index (reflecting the influence of technological working parameters allowing for reducing the consumption of natural resources) makes it possible to perform a thorough analysis of the options for improving the DHS efficiency by defining factors that are favourable for a rise in eco-intensity. Based on the results of our commercial experiment, the independent variables have been found for the case of the gas condenser without packing.

2. The eco-intensity of a boiler house's operation decreases as the outdoor air temperature falls and it is necessary to charge more fuel into the boiler's furnace; for this, many technical causes exist, from which the parametric deviations of the gas condenser (in the gas condenser without packing case) creates the most impact, first of all those of flue gas velocity and temperature rise.

3. The analysis of the influence exerted by the boiler house's specific load on its operation provides evidence that the greater this load, the lower the relevant eco-intensity and the smaller the amount of heat energy which can be derived from the gas condenser. All this should be taken into consideration when working on the model of the control of the gas condenser operation.

4. The operation of a gas condenser depends on the energy efficiency of DHS users as well as on the water velocities and flows in all the elements of a heat network, including heat exchangers at the heat substations of the buildings.

5. To raise the amount of heat derived from a gas condenser, it is necessary to reduce the DHS returned water temperature. This could be done by the qualitative and quantitative modelling of the DHS operating conditions and control over its functioning.

6. As shown in the example of Ludza, the evaluation of eco-intensity of existing systems can be obtained experimentally. For alternative heat supply systems the proposed system of equations has to be addressed.

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EKOLOGINIO INTESYVUMO NAMĄ ŠILDANT SKIEDROMIS ANALIZĖ

D. Blumberga, E. Vīgants, I. Veidenbergs, G. Vīgants, V. Vītoliņš

S a n t r a u k a

Ekologinis intensyvumas priklauso nuo šilumos tiekimo sistemos elementų sąveikos ir jų bendro veikimo. Tai ypač svarbu tiriant galimybes sumažinti skiedrų kuro sąnaudas tuo atveju, kai šildomame name yra įdiegtas papildomas elementas – dujų kondensatorius. Sistemos veikimo efektyvumas įvertinamas pagal jos ekologinį intensyvumą; tokie vertinimai susiję su įtaka technologiniams parametrams mažinant gamtinių išteklių naudojimą. Remdamiesi tyrimo duomenimis, autoriai nustatė nepriklausomuosius dujų kondensatoriaus kintamuosius.
Šildomo namo ekologinis intensyvumas susijęs su lauko temperatūra. Kai ji nukrinta, apkrova turėtų būti padidinama. Tai lemia kelios priežastys, iš jų svarbiausios: dujų kondensatoriaus darbinių parametrų nuokrypiai, išmetamųjų dujų greičio padidėjimas ir temperatūra. Atlikta analizė parodė, kad didinant katilo formą, sistemos efektyvumas mažėja, ir todėl mažiau šilumos energijos tiekiama iš dujų kondensatoriaus. Tai turėtų būti įtraukta į dujų kondensatoriaus veikimo kontrolės modeliavimo skaičiavimus.

Reikšminiai žodžiai: dujų kondensatorius, skiedromis šildomas namas, šilumos tiekimo sistema, optimizacija, ekologinis intensyvumas, komerciniai tyrimai, aplinkos tausojimas.

Dagnija BLUMBERGA. Dr Habil, Professor and Director of the Institute of Energy Systems and Environment, Riga Technical University (RTU). Doctor Habilitus Thesis "Analysis of Energy Efficiency from Environmental, Economical and Management Aspects" was prepared in Royal Institute of Technology (KTH), 1995 and was defended at RTU, 1996. PhD thesis "Research of Heat and Mass Transfer in Gas Condensing Unit" was defended at Lithuanian Energy Institute, 1988. First degree in Thermal Engineering (RPI, now RTU), 1970. The main research area is renewable energy resources. She has participated in different local and international projects related to energy and environment as well as she is author of more than 200 publications and 14 books.

Edgars VĪGANTS. Master, PhD student (since 2008) and researcher, Institute of Energy Systems and Environment, Riga Technical University (RTU). Member of the board, SIA "Ludzas Bio-Enerģija", Latvian Bio Energy Association. Master of Environmental Science, RTU, 2008. First degree in Heating, Gas and Ventilation Systems Construction Engineering (RPI, now RTU), 1983. Research interests: cogeneration, renewable energy resources, energy efficiency and climate technologies.

Ivars VEIDENBERGS. Dr Habil, Professor, Institute of Energy Systems and Environment, Riga Technical University (RTU). Doctor Habilitus Thesis "Engineering Methods for Calculating Heat and Mass Transfer in the devices of Power Units" was defended at RTU, 1992. PhD thesis "Dynamic Temperature Regimes of Thermoelectric Cooling Devices" was defended at RPI, now RTU, 1975. First degree in Thermal Engineering (thermal equipment of thermal power stations) (Moscow State University of Railway Engineering), 1960. The main research area is energy and environment. He is author of more than 180 publications and 5 books.

Ģirts VĪGANTS. Master, PhD student (since 2011), Institute of Energy Systems and Environment, Riga Technical University (RTU). Professional Master Degree in Heat, Gas and Water Systems, RTU, 2011. First degree in Heat, Gas and Water Systems and Engineer qualification in Heat, Gas and Water Technology, RTU, 2010. Research interests: district heating, cogeneration, renewable energy resources.

Valdis VĪTOLIŅŠ. Dr, leading researcher, Institute of Energy Systems and Environment, Riga Technical University (RTU). PhD thesis "Optimisation of District Heating System Operation with Biofuel Energy Source" was defended at RTU, 2005. Research interests: district heating, renewable energy resources, energy efficiency, climate technologies.