*Journal of KONES Powertrain and Transport, Vol. 25, No. 2 2018*

**ISSN:** 1231-4005
**e-ISSN:** 2354-0133
**DOI:** 10.5604/01.3001.0012.2795

# NUMERICAL ANALYSIS OF A HEAT TRANSFER IN ECONOMIZER DEDICATED FOR 250 KW POWER SOLID FUEL HEATING BOILER

**Wojciech Judt, Jarosław Bartoszewicz**

*Poznan University of Technology, Chair of Thermal Engineering*
*Piotrowo Street 3, 60-965 Poznan, Poland*
*tel.: +48 61 6652209, +48 61 6652215, fax: +48 61 6652281*
*e-mail: wojciech.judt@put.poznan.pl,*
*jaroslaw.bartoszewicz@put.poznan.pl*

### *Abstract*

*Heating boilers, which are combusting solid fuels, are a very popular heating device in Poland. Heating boilers for solid fuels with nominal power equal to 250-300 kW reach a high level of waste heat. Polish companies produced a significant amount of heating boilers with that level of heating power, which are being exploited all the time in smaller companies and housing associations. A temperature of exhaust gases in the outlet of the heating boiler can be equal to 270-300°C. It means that it is possible to recover some part of the waste heat. It can be realizable in an external heat exchanger. The article contains a methodology of a heat transfer process calculation for this type of heat exchangers. Estimated waste heat, which can be recovered from this installation, is equal to 25 kW. Additional heat exchanger implementation into a plant can increase an efficiency of solid fuel combustion process for a 10 percent. Construction of a heat exchanger was calculated during analytical calculations. After that, analytical calculations were verified in numerical calculations. Numerical analysis of a heat exchanger model was realized in the ANSYS Fluent environment. During calculations, a shell-and-tube heat exchanger construction was analysed. Authors of the article analysed a real temperature distribution for exhaust gases located on a shell side and for a water, which are located on a tube side of the economizer. Numerical calculations allowed to model conditions of economizer steady state work for a whole volume of this construction.*

***Keywords:*** *heating boiler, heat transfer, economizer, fluent, solid fuel*

## 1. Introduction

Polish companies, which are producing heating boilers had or still have in his offer chopper boilers for solid fuels with nominal power equal to 250-300 kW. This type of heating boilers was offered by many producers from Poland. This construction is adapted for combustion of all types of solid fuels. Some part of these heating devices is still used for heating processes in production halls of companies, bigger houses, or housing associations. Analysed construction of heating boiler reach a significant temperature of exhaust gases, which is an effect of low efficiency of realized combustion process. One of construction of heating boiler, which was producing in polish companies was construction of MarCo heating boiler. According to heating boiler documentation this construction has nominal power equal to 250 kW. Supposed by producer temperature of exhaust gases in the outlet from heating boiler is equal to 270-300°C [2]. This big amount of temperature of fumes, which are exiting from heating boiler, causes, that is possible to recover a part of waste heat. It is possible after application of external heat exchanger into analysed installation. Scheme of proposed solution for an efficiency increasing is shown in Fig. 1.

Hot exhaust gases, which are escaping from heating boiler are directing into shell side of economizer. For a heat recovering in economizer a water, which are cooling heating boiler was applied. Hot water is flowing from heating boiler to heat recipient and after cooling, is directed into tube side of analysed heat exchanger. Water, which is flowing through economizer, is heated by fumes; and recovers a part of waste heat from exhaust gases. After that water is directed into

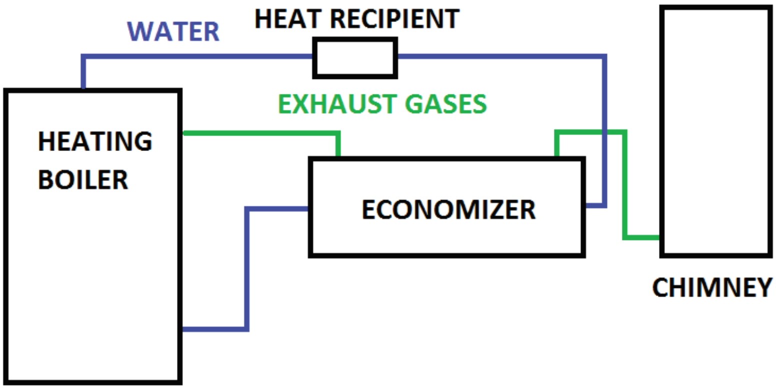

*Fig. 1. Scheme of waste heat recovering installation*

heating boiler for cooling processes. Increasing of temperature of water on inlet to the heating boiler cases growing an efficiency of realized process of heating boiler work.

Polish Standard PN-EN 303-5:2012 inform that secure level of temperature for exhaust gases at the outlet from the heating boiler is equal to 160 ° C above ambient temperature [3]. In this case, the heating boiler is not exposed to a water and acids liquefaction from exhaust gases. The same situation can be assumed for heat exchangers, which through exhaust gases are flowing. Ensuring, that a secure level of exhaust gases temperature at the outlet from heat exchanger will be realizable, then the heat exchanger can be made from the cheaper material, which is not immune to corrosion influence. Application of such a procedure allows for increasing a rate of investment return.

Estimation of benefits for an external heat exchanger implementation into installation is based on increasing of efficiency of the realized process in the heating boiler. Calculation of heating power, which can be recovered from exhaust gases, can be computed from Eq. (1):

$$P = \dot{m} \cdot c_p \cdot \Delta t, \tag{1}$$

where:
$P$ – heating power,
$\dot{m}$ – mass flow of exhaust gases,
$c_p$ – specific heat of exhaust gases,
$\Delta t$ – temperature difference between inlet and outlet of economizer.

Obtained heating power for analysed construction of economizer is equal to 25 kW. This value means, that economizer implementation into installation causes an increase of efficiency of the realized combustion process in the heating boiler for about 10%.

## 2. Analytical calculations

Analytical calculations are based on an Eq. (1) which is describing a heat transfer process for heat exchangers:

$$P = h \cdot A \cdot \Delta t_{log}, \tag{2}$$

where:
$h$ – overall heat transfer coefficient,
$A$ – area of heat transfer,
$\Delta t_{log}$ – logarithmic temperature difference.

Overall heat transfer coefficient is described by Eq. (3) [4]:

$$h = \frac{1}{\frac{d_{śr}}{\alpha_1 \cdot d_{wew}} + \frac{g}{\lambda} + \frac{d_{śr}}{\alpha_2 \cdot d_{zew}}}, \tag{3}$$

where:
$d_{śr}, d_{wew}, d_{zew}$ – average, interior, exterior diameter of the applied tubes in the heat exchanger,
$g$ – thickness of applied tubes,
$\lambda$ – coefficient of thermal conductivity for a tube material,
$\alpha_1$ – heat transfer coefficient for a fluid located on a tube side of economizer,
$\alpha_2$ – heat transfer coefficient for a fluid located on a shell side of economizer.

Authors assumed that thickness of implemented tubes into economizer was equal to 2 mm. According to heat exchanger realization from carbon steel, a thermal conductivity for a tubes material is equal to $52\ \mathrm{W\cdot m^{-1}\cdot K^{-1}}$. Interior diameter of applied tubes is equal to 11 mm. This diameter is used also as a characteristic dimension for a Reynolds number calculation.

The logarithmic temperature difference between analysed fluids is equal to 174ºC and is based on assumed temperatures of water and exhaust gases at inlet and outlet of the heat exchanger. Calculation of overall heat transfer coefficient requires computing coefficients of heat transfer for respective fluids, which are taking parts in heat transfer process. Values of heat transfer coefficients are calculated by experimental equations for Nusselt number computation, based on Reynolds and Prandtl number [1, 4]. Assumed data for analysed fluids, which are needed for analytical calculations, are shown in Tab. 1.

Table 2 is showing results of realized analytical calculations for designed construction of heat exchanger.

*Tab. 1. Assumed parameters for analytical calculations of heat exchanger design*

| Parameter | Water | Exhaust gas |
|---|---|---|
| The temperature at the inlet to heat exchanger [ºC] | 68 | 300 |
| The temperature at the outlet from heat exchanger [ºC] | 75 | 200 |
| Mass flow [kg/s] | 0.5 | 0.2 |
| Specific heat $[\mathrm{J\cdot kg^{-1}\cdot K^{-1}}]$ | 4200 | 1080 |
| Density $[\mathrm{kg/m^3}]$ | 1000 | 0.64 |
| Thermal conductivity $[\mathrm{W\cdot m^{-1}\cdot K^{-1}}]$ | 0.66 | 0.04 |
| Prandtl number [–] | 2.1 | 0.67 |
| Kinematic viscosity $[\mathrm{m^2/s}]$ | $3.4\cdot10^{7}$ | $3.3\cdot10^{5}$ |

*Tab. 2. Results of analytical calculations*

| Parameter | Water | Exhaust gas |
|---|---|---|
| Reynolds number [–] | 4600 | 2300 |
| Nusselt number [–] | 27 | 18 |
| Heat transfer coefficient $[\mathrm{W/(m^2\cdot K)}]$ | 1600 | 48 |
| Overall heat transfer coefficient $[\mathrm{W/(m^2\cdot K)}]$ | 46 | |
| Length of economizer [m] | 1.2 | |
| External diameter of economizer [m] | 0.18 | |
| Heating power [kW] | 18 | |

Scheme of designed construction of economizer is shown in Fig. 2. Fluid flow in the economizer is realized as counter current. Exhaust gases are flowing through 6 sections of the heat exchanger. Water flow inside economizer is realized through 36 pipes, which are cooling exhaust gases. The flow of exhaust gases is realized on right angle to flow of water.

Shell and tube construction of the heat exchanger is a good solution for a heat transfer between gaseous and fluid mediums. Exhaust gases have more volume than water and they reach a higher velocity of a flow. Then, it is better to locate this fluid on a shell side of designed heat exchanger.

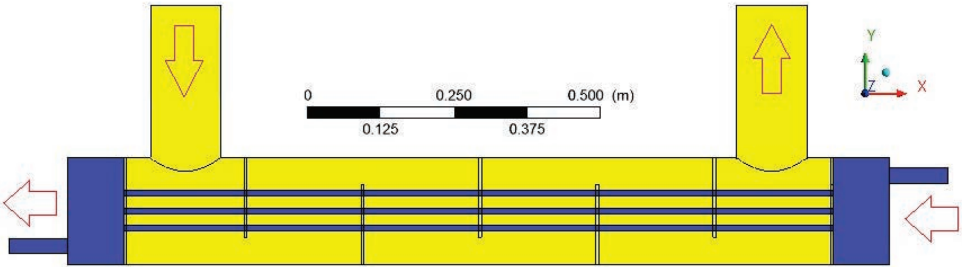

*Fig. 2. Scheme of analysed construction of the heat exchanger*

During analytical calculations, authors estimated that a proposed construction of heat exchanger could recover 18 kW of heating power from exhaust gases. Calculations were realized for assuming, that a temperature of exhaust gases at the outlet is equal to 200ºC. It is possible to obtain more value from heat exchanger usage for this installation when a temperature of exhaust gases at the outlet will be lower. Also implemented the methodology of calculation has not big accuracy. A mistake for experimental equations, which are using for Nusselt number calculation, is equal about 20%. Good solution for an analytical computation verification is realizing a numerical analysis of the analysed case of heat transfer process.

## 3. Methodology and results of numerical calculations

Numerical calculations were realized in the ANSYS Fluent environment. Mesh, which was created for numerical calculations was realized as structural. Calculations were realized for a three-dimensional model. A numerical model was implemented as a steady state. The turbulence of a flow in a heat exchanger was solved by a k-Epsilon turbulence model implementation. Heat transfer process in a numerical model was realized as an interface between two domains, representing exhaust gases and water located in a heat exchanger volume. Diaphragm influence for a heat transfer process is implemented as a model in the interface as a steel wall with 2 mm thickness. Exterior walls of the heat exchanger are implemented to a model as adiabatic. The temperature of exhaust gases at the inlet to the heat exchanger geometry is equal to 300ºC. Temperature of water, which is flowing through a pipe side of the heat exchanger at the inlet, is equal to 68ºC. The mass flow of water and exhaust gases in the analysed numerical model is similar to analytical calculations and is equal to 0.5 kg/s for a water and 0.2 kg/s for exhaust gases. The temperature at the outlet results from prepared numerical calculations; and cannot be assumed in this approach to the analysed problem.

Figure 3 presents a temperature distribution obtained during numerical calculations for exhaust gases in the analysed construction of economizer.

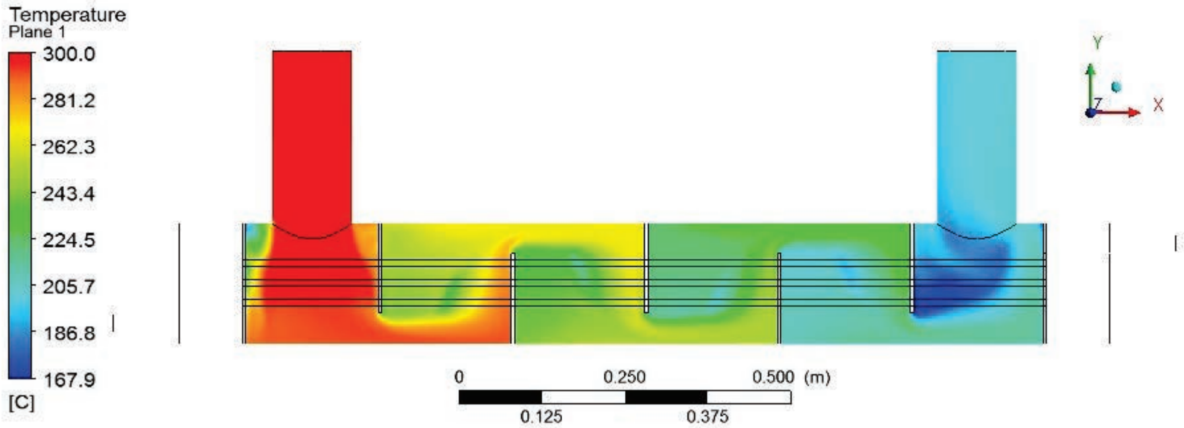

*Fig. 3. Temperature distribution for exhaust gas located on a shell side of the heat exchanger*

Realized numerical model showed, that temperature distribution of exhaust gases in the analysed heat exchanger is changing from 300ºC to 168ºC. The temperature of exhaust gases is gradually decreasing to about 20ºC for each section of the economizer. The coolest place for each section of the heat exchanger is located in the centre of the sections, between the pipes. The average temperature of exhaust gases obtained for an outlet from the heat exchanger is equal to 199ºC. The lowest temperature of exhaust gases is higher than assumed 160ºC, which causes problems with corrosion in steel constructions after water and acids liquefaction from exhaust gases.

Figure 4 presents a temperature distribution, which was obtained from numerical calculations for water located on a tube side in the analysed construction of economizer.

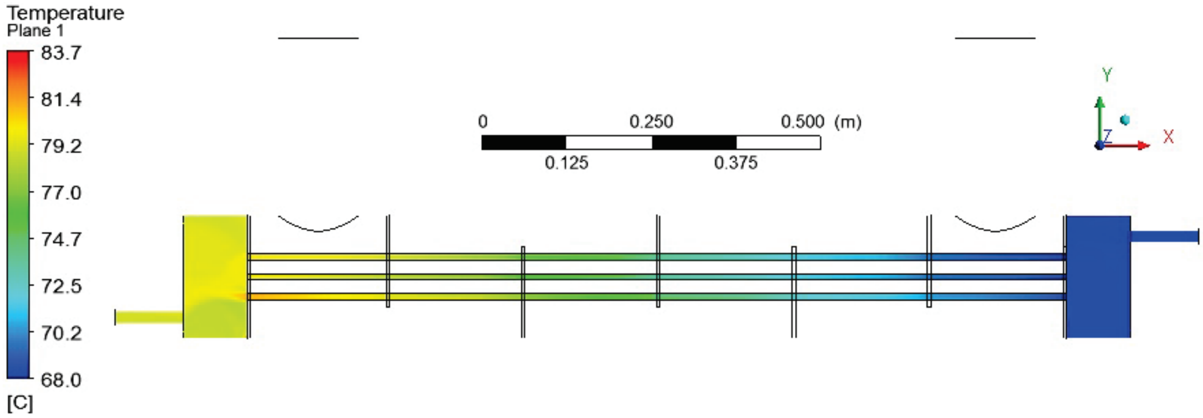

*Fig. 4. Temperature distribution for a water located on a tube side of the heat exchanger*

Numerical analysis showed that temperature distribution of water in the analysed construction of economizer is changing from 68 º C to 84 º C. The temperature of exhaust gases is gradually increasing. The average temperature of water at the outlet from heat exchanger construction is equal to 78ºC. Analysis of temperature difference for a water between inlet and outlet causes, that is possible to calculate the heating power of designed economizer based on numerical calculations. This value is calculated in the same process as in analytical calculations from Eq. (1). Obtained in numerical calculations value of power, which can be recovered from exhaust gases is equal to 21 kW.

## 4. Conclusions

Numerical modelling implementation into a heat exchangers designing process allows supporting a designer work and causes, that this process can be realized more effectively. Numerical model verified and covered obtained results from analytical calculations. The temperature in the outlet from economizer obtained from numerical calculations was the same as from the analytical calculations. It means that numerical model was prepared with the right accuracy and applied mesh into the model was optimal. Implementation of the economizer into analysed installation increases an efficiency of the heating boiler for about 8.4%. Numerical model preparation allows obtaining more results for analysed model

## References

[1] Gogół, W., *Wymiana ciepła – tablice i wykresy*, Wydawnictwa Politechniki Warszawskiej, Warszawa 1991.
[2] Lumo Technika Grzewcza, *Dane dla projektantów, Stalowe wodne kotły grzewcze Lumo typoszeregu 8-300 kW MarCo*, online: http://www.lumo.com.pl/pdf_techniczne/marco.pdf, 2006.

[3] PN-EN 303-5:2012 *Kotły grzewcze – Część 5: Kotły grzewcze na paliwa stałe z ręcznym i automatycznym zasypem paliwa o mocy nominalnej do 500 kW – Terminologia, wymagania, badania i oznakowanie,* 2012.
[4] Staniszewski, B., *Wymiana ciepła, podstawy teoretyczne*, Państwowe Wydawnictwa Naukowe, Warszawa 1979.
[5] Wiśniewski, S., Wiśniewski, T., *Wymiana ciepła*, WNT, Warszawa 2009.

*Manuscript received 10 March 2018; approved for printing 29 June 2018*