PROPOSAL OF THE COMBINED EXHAUST GAS HEAT EXCHANGER AND THE MUFFLER

Miloš BREZÁNI, Peter BARAN, Róbert LABUDA
University of Zilina, Faculty of Mechanical Engineering
Univerzitná 1, 010 26 Žilina, Slovakia, e-mail: milos.brezani@fstroj.uniza.sk, peter.baran@fstroj.uniza.sk, robert.labuda@fstroj.uniza.sk

Abstract

The article discusses about the design of a combined exhaust gas heat exchanger with muffler. The first stage deals with the calculation of the exhaust gas heat exchanger according to the required parameters. The next step addresses the structural design of the exhaust gas heat exchanger according to the parameters of the calculation. Subsequently creation a 3D model, which will be used for the simulation of flow of the working substance in the heat exchanger and heat transfer simulation of the media. The simulations are solved in a 3D simulation program COMSOL Multiphysics 5.0. Further solves the structural design of muffler, which will form a part of the exhaust gas heat exchanger. Subsequently execution of the measurements on the real model of the combined exhaust gas heat exchanger to verify the accuracy of calculations, simulations and structural designs.

Key words: Exhaust gas heat exchanger, Muffler, Simulation, 3D model, Structural design

PROJEKT ZINTEGROWANEGO WYMIENNIKA CIEPŁA SPALIN WRAZ Z TŁUMIKIEM

Streszczenie

W artykule omówiono projekt zintegrowanego wymiennika ciepła spalin wraz z tłumikiem. Pierwszy etap dotyczył obliczania wymiennika ciepła spalin w zależności od wymaganych parametrów. Następnym krokiem było stworzenie projektu konstrukcyjnego wymiennika ciepła spalin według parametrów z obliczeń. Następnie stworzono model 3D, który był wykorzystany do symulacji przepływu substancji roboczej w wymienniku ciepła oraz do symulacji transferu ciepła mediów. Symulacje są wykonywane w programie do symulacji 3D - COMSOL Multiphysics 5.0. Dalej wykonano projekt konstrukcyjny tłumika, tworzący całość z wymiennikiem ciepła spalin. Następnie wykonano pomiarów na rzeczywistym obiekcie zintegrowanego wymiennika ciepła spalin z tłumikiem, w celu sprawdzenia poprawności obliczeń, symulacji i projektu konstrukcyjnego.

Słowa kluczowe: wymiennik ciepła spalin, tłumik, symulacja, model 3D, projekt konstrukcyjny

INTRODUCTION

Nowadays, the exhaust gas heat exchanger are increasingly used in various applications of devices around us. Use of this technology most often, appears in cogeneration units [4] as a node for recapture of waste heat from the exhaust gases [8]. However cases of using this technology in the automotive industry have already occurred, for example BMW technology Turbosteamer [6]. Because the exhaust gas heat exchanger can't muffle the noise generated by the exhaust gases it is needed to retrofit muffler. Because of the use of the heat exchanger [1] in smaller facilities it is desirable that it has compact proportions and not occupies too much space. A combined proposal of heat exchanger and the muffler could solve this problem. Its construction should prove especially for smaller cogeneration units [10] or the car itself.

1. Calculation and draft of the exhaust gas heat exchanger

The created draft of the exhaust gas heat exchanger according to following input parameters (Tab. 1).

Table 1: Input parameters for the draft of the exhaust gas heat exchanger [2]

		Exhaust gas side		Cooling liquid side	
Required power	4,4 kW	Flow	82,5 m^3/h	Flow	0,69 m^3/h
		Inlet temp.	584 °C	Inlet temp.	89,5 °C
		Outlet temp.	≈115 °C	Outlet temp.	≈95,6 °C

Based on the input values we calculated the parameters of the exhaust gas heat exchanger which are given in Table 2.

Table 2: Calculated parameters of the exhaust gas heat exchanger

Structural design	
Calculated power	4,8 kW
Number of pipes	48
Length of heat exchanger	1000 mm
Volume of heat exchange area	2,03 m^2

Based on the calculated parameters we suggested and modelled the exhaust gas heat exchanger (Fig. 1).

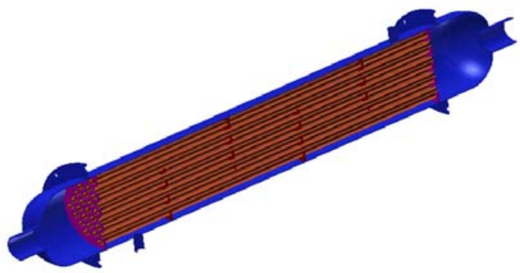


Fig. 1: 3D model of designed exhaust gas exchanger

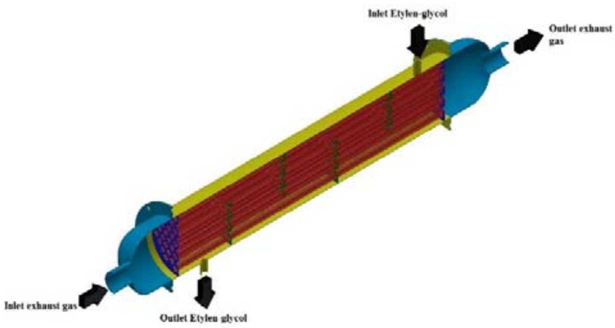


Fig. 2: Flow direction of working substances cross the heat exchanger [6]

Flow direction of working substance (etylen-glycol) cross the heat exchanger was chosen like a counter-flow how you can see in Fig. 2.

2. Simulation of energetic ratios of the exhaust gas heat exchanger

On the proposed exhaust gas heat exchanger was made simulations of flow of exhaust gases and heat transfer in a 3D simulation program COMSOL Multiphysics.

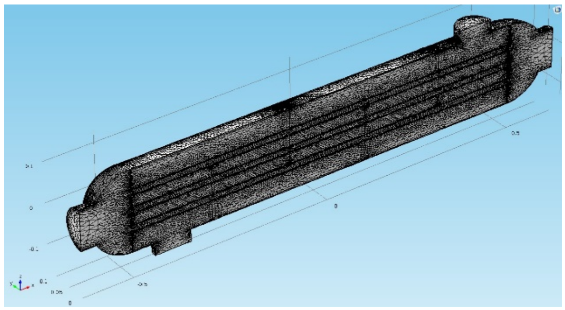


Fig. 3: Layering of the mesh in the model

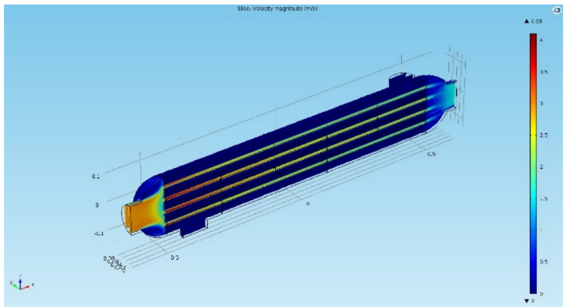


Fig. 4: Simulation of velocity magnitude of the exhaust gas heat exchanger in m/s

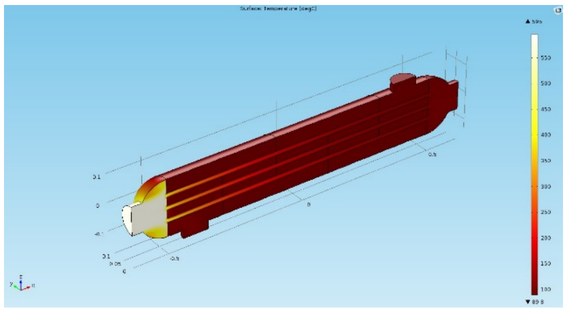


Fig. 5: Temperature of the exhaust gas heat exchanger in °C [6]

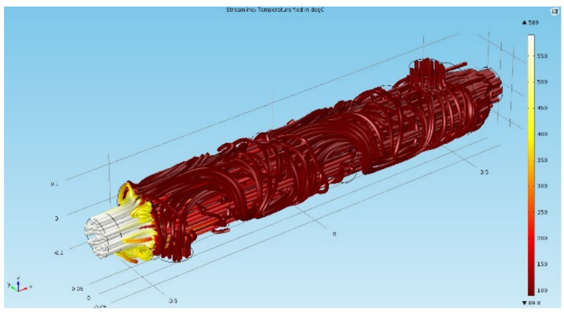


Fig. 6: Streamline in the exhaust gas heat exchanger

In the Fig 7 we can see comparison between maximum and minimum inlet a) and outlet b) temperature of cooling liquid. The inlet temperature is 363 K (89.85 °C) and mean outlet temperature is 370 K (97 °C). Additionally on Fig 7 c) comparison between the inlet temperatures is presented and Fig 7 d) presents comparison between the outlet temperatures of exhaust gas. The mean inlet temperature is 857 K (584 °C) and the mean outlet temperature is 373.3 K (98.2 °C). The simulation shows that the draft is correct, because the outlet temperatures of working substance are very similar to the required parameters. The half-circles interpret inlets and outlets of both working substances. The 3D model used in simulation is in longitudinal section therefore the inlets and outlets of heat exchanger are not presented as circle but as half-circle. The axis in Fig 7 express only diameter (m) of inlets and outlets of heat exchanger for better position determination of temperature points.

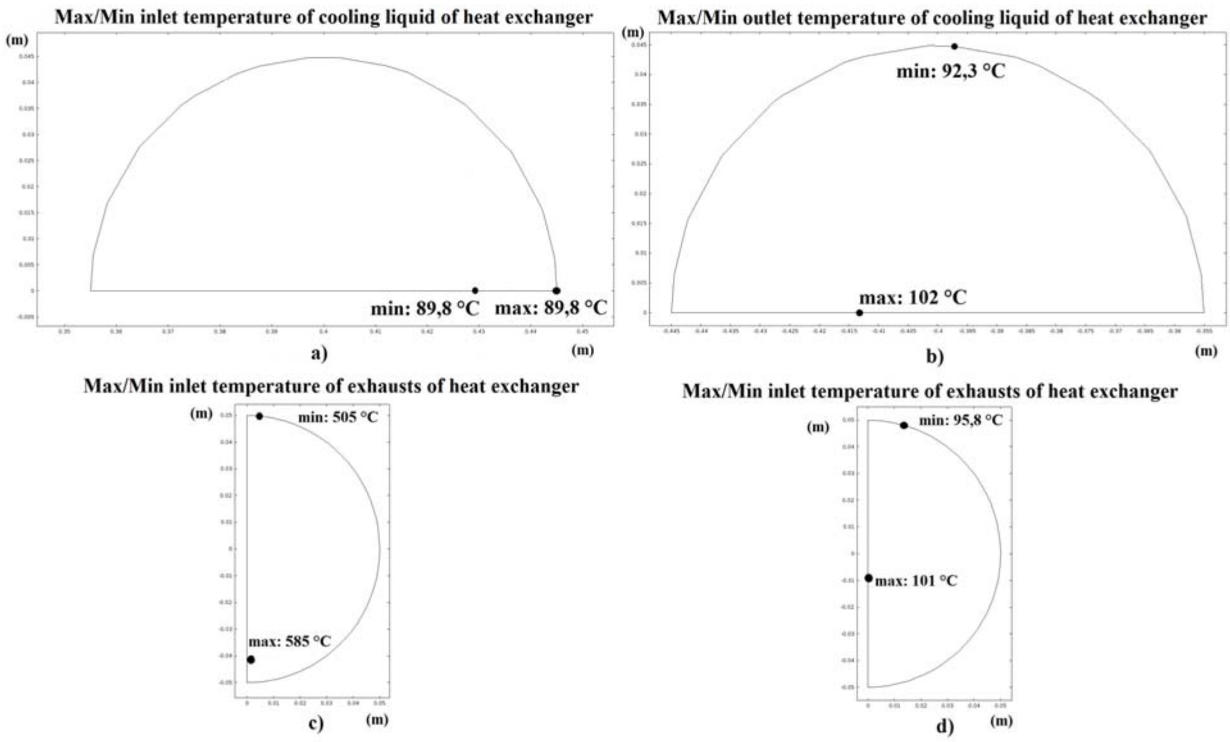


Fig. 7: Comparison of the temperatures between inlet and outlet working substances

$$Q_1 = Q_2 = Q \tag{1}$$

Q_1 [W] – heat input supplied by working fluid
Q_2 [W] – heat power transferred to the cooling liquid
Q [W] – heat power of the exhaust gas heat exchanger [3]

To calculate heat output Q we need to use equation (1) and need to know these Q_1 and Q_2 values calculated from the following relationship:

$$Q_1 = m_1 \times c_{p1} \times (t_{s1} - t_{s2}) = 17895{,}33\ kJ/h \tag{2}$$

Q_1 [W] – heat input supplied by working fluid
m_1 [kg.h^{-1}] – mass flow of the working fluid
c_{p1} [kJ.kg^{-1}.K^{-1}] – specific heat capacity at constant pressure
t_{s1} [W] – inlet temperature of the working fluid
t_{s2} [W] – outlet temperature of the working fluid

The Q_2 value was calculated by the same equation and to equation were appointed parameters for cooling liquid. The value Q_2 then will be 17877,4 kJ.h^{-1}. After appointing into equation (3) we get:

$$Q_1 = Q_2 = Q \rightarrow 17895 = 17877 = Q \tag{3}$$
$$Q = 17895\ kJ/h \rightarrow 4{,}97\ kW$$

Table 3: Comparison of the heat power detected from the simulation and from the calculation.

The heat power detected from the simulation	The heat power detected from the calculation
Q = 4970 W	Q = 4775 W

Comparison of simulation results with the calculations showed that we proceeded correct. And the values detected by calculations are with a small variations identical like values detected from the simulation COMSOL Multiphysics 3D.

3. Draft of the muffler

Because the muffler will be a part of the heat exchanger of cogeneration unit with diesel engine which produce low-frequency noise in range 100 - 1000 Hz. [5] Therefore, it is necessary to design the muffler for damping low-frequency sound.

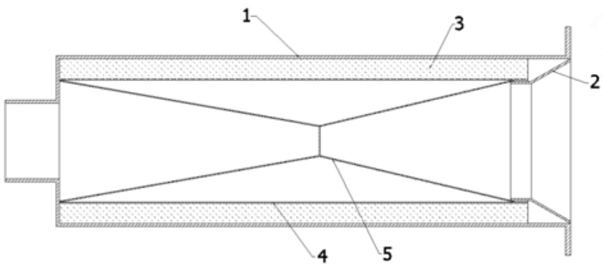


Fig. 8: Longitudinal section of muffler 1 - outer shell, 2 - reduction, 3 - noise - absorbing material, 4 - inner shell made from perforated sheet metal, 5 - inner cone from perforated sheet metal.

Fig. 9: 3D model of the muffler

Inside of the muffler was used perforated sheet metal and sound - absorbing material based on glass wool Fig. 11

Fig. 10: Parts of muffler

Fig. 11: Glass wool inside of muffler

The muffler is designed as a part of the exhaust gas heat exchanger. The muffler will be mounted instead of the rear cover of the heat exchanger (Fig. 13), thus achieving the elimination of external muffler as another device in the exhaust tract of a cogeneration unit. [9]

Fig. 12 The muffler (right) in comparison with rear cover of the heat exchanger (left)

Fig. 13 The muffler mounted on the heat exchanger

4. Measurement of cogeneration unit noise

Noise of cogeneration unit was measured twice. The first measurement was without a muffler and a second measurement with muffler. Measured values of noise, were evaluated and inserted to the graphs.

To perform frequency analysis, the measuring device from the company Brüel & Kjaer "Integrating sound level meter set 2218" with "1/3 octave filter set 1616" was used.

Fig. 14 The measure instrument Brüel & Kjaer

The measuring apparatus was placed under 45 ° angle at a length 50 cm and height 20 cm from the free end of the exhaust pipe as can be seen in Fig. 15. Placing a measuring instrument was in accord to Directive 2007 /46 / EC which gives information about noise measurement of motor vehicles [7].

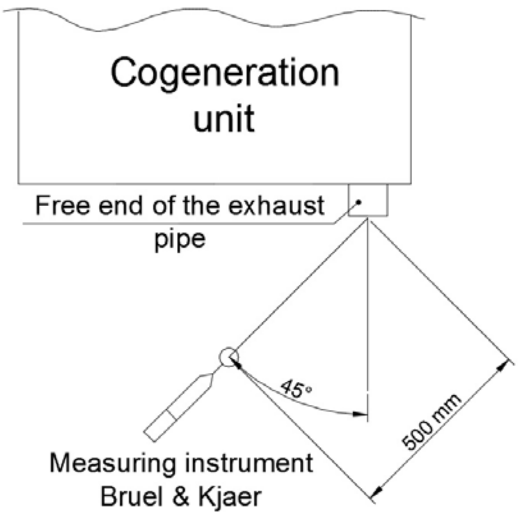


Fig. 15: Measurement scheme

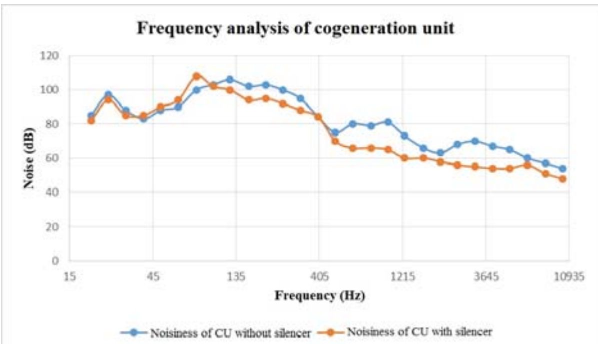


Fig. 16: Graph of the frequency analyse

Table 4: Noisiness comparison of cogeneration unit with and without muffler

Frequency (Hz)	Noisiness (dB)		
	Without muffler	With muffler	Absorption
20	85	82	3
25	97	94	3
32,5	88	85	3
40	83	85	-2
50	88	90	-2
63	90	94	-4
80	100	108	-8
100	103	102	1
125	106	100	6
160	102	94	8
200	103	95	8
250	100	92	8
315	95	88	7
400	84	84	0
500	75	70	5
630	80	66	14
800	79	66	13
1000	81	65	16
1250	73	60	13
1600	66	60	6
2000	63	58	5
2500	68	56	12
3150	70	55	15
4000	67	54	13
5000	65	54	11
6300	60	56	4
8000	57	51	6
10000	54	48	6

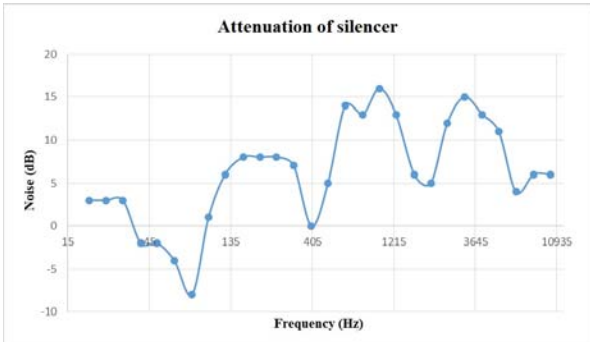


Fig. 17: Graph of the muffler absorption

5. SUMMARY

The aim of work was based on the input parameters to calculate and design a 3D model of the combined proposal of the exhaust gas heat exchanger and the muffler. Authors performed simulation of the proposed model in COMSOL Multiphysics. After verifying the correctness of the draft created by the simulations real model of combined facility was made. Subsequently was performed the measurement of the combined facility mounted to the real combustion engine for the purpose of validation of the correctness of the draft. How can be seen on the last picture it is necessary to upgrade the muffler in order to be able to better reduce low - frequency noise.

Acknowledgement:

This contribution is the result of the project implementation: Modern methods of teaching of control and diagnostic systems of engine vehicles, ITMS code 26110230107, supported by the Operational Programme Educational.

REFERENCES

[1] Mičieta J., Lenhard R., Jandačka J.: *The heat exchanger of small pellet boiler for phytomass*. XIX. the application of experimental and numerical methods in fluid mechanics and energetics, 2014 - AIP Conference Proceedings, Vol. 1608. - ISSN 0094-243X).

[2] Brezáni M., Baran P., Labuda R.: *Using of waste heat of internal combustion engines and draft of exhaust gas heat exchanger*. trans&Motauto, 2015

[3] Stehlík P and col.: *Heat transfer processes.* Title of a book. Vysoké učení technické, Brno, 1991.

[4] Brezáni M., Labuda R., and col.: *Using of waste heat of internal combustion engines.* 22nd international scientific and technical conference trans & MOTAUTO, 2014, Varna, Bulgaria. - ISSN 1310-3946.

[5] Nemec J. – Randsdorf J. Šnédrle M.: *Hluk a jeho snižování v technické praxi.* Státní nakladatelství technické literatury, Praha, 1970.

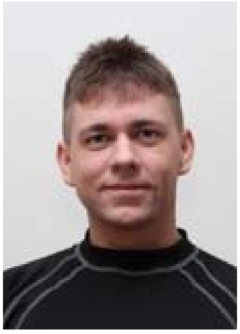
[6] Brezáni M., Baran P., Labuda R.: *Using of waste heat in road vehicles with internal combustion engines*, conference Logitrans, 2015.

[7] Directive 2007 /46 / EC, Directive about noise measurement of motor vehicles.

[8] Holubčík, M.- Hužvár, J.: Jandačka, J.: *Combined production of heat and electricity with use of micro cogeneration*, IN-TECH 2011 International Conference on Innovative Technologies, rok 2011, s. 200-202, ISBN 978- 80-904502-6-4

[9] Kovalčík, A.: Toporcer, E.: Hlavňa, V.: *Gaseous emissions of a combined cogeneration unit*, In: TRANSCOM 2009 : 8-th European conference of young research and scientific workers : Žilina June 22-24, 2009, ISBN 978-80-554- 0031-0. – S. 43-46.

[10] Nemec, P.: Hužvár, J.: *Proposal of heat exchanger in micro-cogeneration unit, configuration with biomass combustion* In: Development of materials science in research and education : the nineteenth joint seminar. – [Bratislava: Slovak Society for Industrial Chemistry, 2009]. - ISBN 978-80-89088-81-2. – S. 28-29.



Miloš BREZÁNI graduated M.Sc. degree at University of Žilina, Faculty of Mechanical Engineering. This time he is studying 3-rd degree university studies at the department Transport and Handling machines. His research interests are in the area of internal combustion engines, diagnostics and road vehicles.