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Preliminary communication

FLUE GAS – ORGANIC FLUID HEAT EXCHANGER OPTIMIZATION FOR MIDDLE – TEMPERATURE ORGANIC RANKING CYCLE

PETR MYDLIL, JAKUB MAŠČUCH

University Centre for Energy Efficient buildings, Czech Technical University in Prague, Czech Republic
e-mail: petr.mydlil@uceeb.cvut.cz

The paper describes the process of optimizing flue gas – organic fluid heat exchanger for the unit operating on the principle of the Organic Rankin Cycle (ORC).The unit was designed to use waste heat from flue gases of the microturbine with an output of 28 kW electrical. At first,dimensions and internal configuration were optimized.Then the parameters of the thermal cycle in terms of their impact onthe return of investments of proposed ORC unit were optimized. The purpose of the paper is to describe how to find optimal configuration of the ORC device.
Key words: organic Rankine cycle, wound heat exchanger, optimization,waste heat recovery.

Optimizacija izmjenjivača topline između dimnih plinova i organske tekućine za srednje temperaturni Rankingov organski ciklus. U radu se opisuje proces optimizacije izmjenjivača topline između dimnog plina - organske tekućine za jedinicu koja radi na principu Rankinovog organskog ciklusa (ORC). Uređaj je dizajniran za korištenje otpadne topline iz dimnih plinova mikroturbine s izlaznom električnom snagom od 28 kW. Najprije su optimizirane dimenzije i unutarnja konfiguracija. Tada su optimizirani parametri toplinskih ciklusa u smislu njihovog utjecaja na povratak investicije predložene ORC jedinice. Cilj ovog rada je opisati kako pronaći optimalnu konfiguraciju ORC uređaja.
Ključne riječi: Rankinov organski ciklus, spiralni izmjenjivač topline, optimizacija, gospodarenje povratom topline.

INTRODUCTION

Currently we can see increasing interest of industrial companies in the use of waste heat. It is probably caused by the rise in price of electricity and fuels. On the other hand, the production costs of technologies and technological units, which can be used for waste heat recovery (WHR), dropped significantly. The cost of installed kW electrical grows much slower with dropping total installed electrical power than in the past [1].

One of the possibilities of waste heat recovery is production of electricity by using unit working on Organic Rankine Cycle principle (ORC). The article describes a model combination of microturbine and ORC unit which utilizes waste heat from flue gases. The microturbine Capstone C30 on power 28 kW electrical was chosen. The thermal power in waste heat, which can be used for electricity generation in ORC unit, is about 50 kW. The microturbine alone achieves 25% electrical efficiency. That is significantly less than the combustion engine, which is used much more often. Increasing the efficiency by using the ORC unit could significantly increase micro-turbine chance of market success. It can be assumed that there will be an increase in efficiency of about 7 percentage points.

The article is focused on the optimization of the flue gas heat exchanger, which is used as an evaporator and economizer of the organic fluid, particularly hexamethyldisiloxane. The goal is to achieve optimal internal configuration and parameters of the thermal cyclewith respect to economic efficiency.

OPTIMIZATION OF THE INTERNAL CONFIGURATION

A wound heat exchanger was chosen. This type is commonly used in cryogenics. The internal dimensions are defined on Fig. 1.

Series of graphs were made that show the dependence of important parameters (specifically heat transfer coefficient k, pressure drop in the flue gas and in the working fluid, height and weight of heat exchanger) on the internal dimensions (x_1 – tubes distance in the transverse direction of gas flow, x_2 – tubes distance in the longitudinal direction of the gas flow, D_{tr} – outer diameter of the tubes, d_0 – diameter of the inner cylinder, number of pipe helices – on Fig. 1there is a 3 – helices variant).

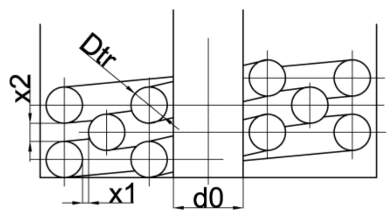

Figure 1. Internal configuration of wound HE
Slika 1. Unutarnja konfiguracija spiralnog izmjenjivača topline

The result of this optimization is Tab. 1, which indicates a range of internal dimensions, which are suitable for further process optimization. The table also shows the impact of changes in the internal dimension of the heat exchanger on the increase / decrease of the height of the heat exchanger (**ΔL_{vym}**), exchanger mass (**Δm**), the pressure drop on the exhaust (**$\Delta(\Delta p_{sv})$**) and the pressure drop of working fluid (**$\Delta(\Delta p_{tr})$**).

Table 1. The influence of internal dimensions
Tablica 1. Utjecaj unutarnjih dimenzija

	Range of dimensions	Increment		Change							
		abs.	relat.	ΔL_{vym}		Δm		$\Delta(\Delta p_{sv})$		$\Delta(\Delta p_{tr})$	
	mm	mm	%	m	%	Kg	%	Pa	%	Pa	%
x_1	3 to 7	1	33	0,141	9,8	32,5	11,3	-745	-19,1	140	11,2
x_2	3 to 7	1	33	0,067	3,9	4,7	1,3	12	0,7	11	0,7
d_0	200 to 300	20	30	-0,070	-3,4	5,6	1,7	-304	-9,7	-2	-0,1
D_{tr}	25 to 35	5	25	0,245	14,8	67,0	24,1	-215	-8,7	-1 659	-41,2

TECHNICAL – ECONOMIC OPTIMIZATION

Optimizing internal dimensions of the exchanger was madefor achieving constant parameters of thermal cycle. Thermal cycle parameters (specifically pinch point, outlet temperature of flue gas from heat exchanger, condensing temperature, output temperature difference in heat recovery exchanger)significantly affect both the annual profit from the sale of electricity and the capital costs of the unit. That´s why the parameters of the cycle have been optimized from the perspective of the shortest return of investment. It was supposed to generate only electricity without using waste heat for heating.

Estimated capital costs arecomposed of items with fixedprice (expansion machine, pump, instrumentation, valves, working medium, devices for removal of heat from condensation, thermal insulation) and the price of heat exchangers, that is dependent on the parameters of thermal cycle. The total price of the device is definedby material costs. The article is focused on flue gas heat exchanger optimization, but for technical-economic optimization it is necessary to consider the whole unit.

In the calculation of the annual produced electricity, theself consumption of cooling system for heat dissipation from condenser, which is transferred into the atmosphere over the water circuit,was considered. The self consumption includes the power consumption of fans and water pump.

The annual amount of produced electricity is considerably dependent on the condensing temperature, which changes with the ambient temperature. That´s why the amount of produced electricity was calculated for each month separately for relevant average ambient temperature (for Central Bohemian Region). It is expected that the operation time will be 8 000 hours per year and purchasing price of electricity 0,12 EUR/kWh. The net produced electricity at constant cycle parameters (pinch point 18°C, outlet temperature of flue gas from heat exchanger 140°C, condensing temperature 40°C, output temperature difference in a heat recovery exchanger 20°C) will be 53 MWh per year with investment costs of 30 000EUR. This corresponds to a simple payback time of 4,8 years. The following charts show changes in the payback time, depending on variable parameters of thermal cycle.

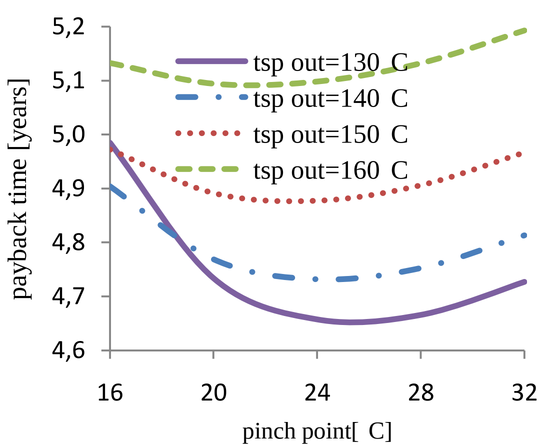

Figure 2. The influence of pinch point on payback time
Slika 2. Utjecaj pinch točke na vrijeme povrata troškova

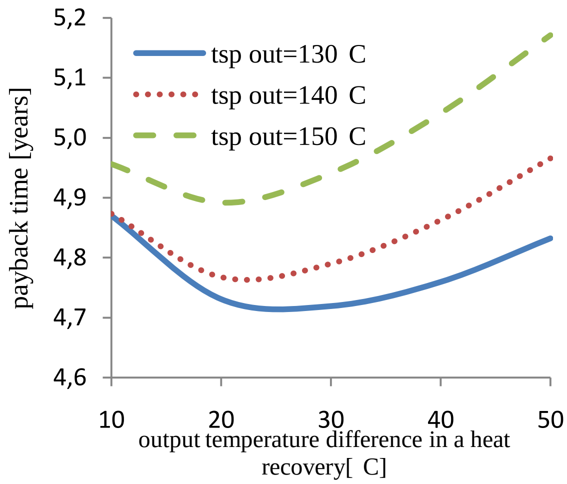

Figure 3. The influence of output temperature difference on payback time
Slika 3. Utjecaj razlike izlazne temperature na vrijeme povrata troškova

From Fig. 2 we can estimate that best parameters are achieved at the pinch point around 24°C and outlet gas temperature (tsp out) 130°C.

The final parameters of the unit after all optimizations are reported below.

Table 2. Final parametres of the unit
Tablica 2. Konačni parametri jedinice

Pinch point	24°C
Flue gas outlet temperature	130°C
Temperature difference at the output of the recovery	20°C
Condensing temperature	40°C
Electric power	7,4 kW
Total weight	350 kg
Cost per unit	29 000EUR
Playback time	4,6 year

CONCLUSION

It is obvious that the optimization of the internal dimensions of the flue gas heat exchanger and parameters of the ORC cycle have to be looked at very complexly. The results of the technical optimization of parameters, such as heat transfer coefficient k, pressure drop, dimensions and weight of heat exchanger, do not necessarily correspond to the optimal parameters in terms of economic efficiency. It is not necessary nor economical to design the unit to the highest degree of utilization of waste heat. Considering usage of waste heat, all fuel costs are equal to zero and any amount of energy, which could be obtained by installing the ORC unit, is increasing fuel efficiency, regardless the efficiency of the transformation. From the perspective of a potential customer the main parameter will be the quantity of electricity, respectively its market value, compared tothe investment costs of the equipment.

Acknowledgement

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REFERENCES

[1] J. Maščuch, J. Hrdlička, Perspektivy mikrokogenerace z biomasy v podmínkách ČR. In: *Technika o chrany prostredia 2009*. Častá - Papiernička, Slovenská Republika, 2009, 337-342.

[2] T. Dlouhy, Tomáš. *Výpočtykotlů a spalinových výměníků*, Vyd. 3. V Praze: Nakladatelství ČVUT, 2007, 212.

[3] P. Mydlil, *Návrh ORC jednotky pro využití odpadního tepla z mikroturbíny*. Praha, 2012. Diplomová práce. České vysokéučení technické, Strojní fakulta.

[4] *Capstone: Turbine Corporation* [online]. 2012 [cit. 2012-10-20], http://www.capstoneturbine.com/