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Use of the Renewable and Waste Energy Sources in Heat Storage Systems Combined with ORC Power Plants

Abstract. *ORC systems are mainly powered from waste and renewable energy sources. In many cases this type of energy sources are specified by the dynamic capacity and thermal characteristics. Such situation has negative influence on ORC power plant working conditions. In this paper the conception of heat storage systems (HSS) combined with the ORC power plants was presented. Use of (HSS) in ORC power plant can improve working conditions and can have influence for raise of the energy generation efficiency.*

Streszczenie. *Najczęściej układy ORC zasilane są przez odpadowe lub odnawialne źródła energii o zmiennych w czasie charakterystykach termicznych wydajnościowych. Mają one negatywny wpływ na warunki pracy układów ORC. W artykule przedstawiono koncepcję wykorzystania systemów akumulacji ciepła skojarzonych z układami ORC. Takie rozwiązanie może poprawić warunki pracy siłowni oraz mieć wpływ na zwiększenie efektywności procesów konwersji energii (**Wykorzystanie odnawialnych i odpadowych źródeł energii w akumulatorach ciepła skojarzonych z układami ORC**)*

Słowa kluczowe: ORC, akumulator ciepła, HSS, analiza termodynamiczna
Keywords: ORC system, heat accumulator, HSS, thermodynamic analysis.

Introduction

Characteristic feature of the ORC systems is their often mating with the heat sources characterized by changeable, dynamic characteristics. Such heat source characteristic in many cases has negative influence for ORC system work conditions, including continuous system operation.

Changeable sources can be found mainly in the group of alternative energy sources. It is possible to consider the changeable characteristic of:
- waste energy sources,
- renewable energy sources.

The first group refers to the heat carriers practically appearing in each industrial energy conversion process, and being the waste of main technological chain. Such refers to the heat collected in the following products: flue gases, cooling mediums, solid waste (slags, coke, etc.) and technical gases with higher thermodynamic parameters than those occurring in the surroundings. In most cases energy from these mediums is not recovered and it is being dissipated to the surroundings. Comprehensively problems connected with industrial waste energy and techniques of its recovery were described in [1], [2], [3] and [4].

The second group is formed by the natural sources with higher thermodynamic parameters than those in surroundings, but occurring periodically. A good example of such source can be the geyser, or solar collector working in changeable insolation conditions and different time of day and a year.

For the economical and energy profitable assessment of this specific energy sources the energetic analyses can be used. Problems connected with this analysis were comprehensively described in [1].

According to the described above problems it is interesting to consider potential of the HSS application in ORC systems. Such solution can enable possibility of changeable heat source characteristic modulation and in the result improve ORC system work conditions.

Heat Accumulators and Heat Storage Systems

Heat accumulators are the devices useful for the effective and long term heat storage and its recovery for further use. Such devices were comprehensively described in [5].

Ideal heat accumulator should be characterized by the following features:
- large heat capacity – obtained by use of the proper construction material and a proper material structure (for ex. honeycomb); the material should have large ability of heat absorption,
- compact dimensions,
- simple construction,
- easiness in assembly and transport,
- large reliability,
- full automation.

Ideal heat accumulator should enable realization of the heat accumulation process without the necessity of phase change in heat accumulating medium - according to isochoric process described by v=idem. equation. In fig.1 the isochoric heat accumulation process on T-s diagram is presented. In fig.2 the comparison with the other thermodynamic processes is presented.

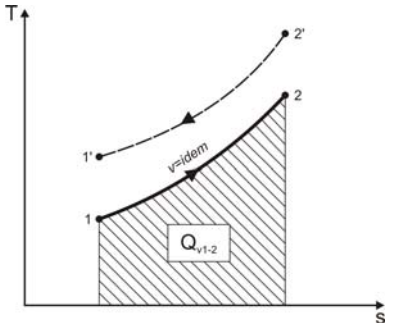

Fig.1. Isochoric heat accumulation process 2'- 1' – cooling of the heat source, 1 - 2 – isochoric heat accumulation process

The heat amount transferred from the heat source to the accumulating medium can be calculated for each of process with help of relation:

$$Q_{1-2} = \int_1^2 T\mathrm{d}s \tag{1}$$

As it can be observed from fig.2 the highest value of accumulated heat is obtained for the isochoric process.

The heat accumulators can be useful for heat storage and its transport for further distances. In this case the heat storage system (HSS) design and construction is needed. The example of HSS can be use of the industrial glycerine, which large amounts are produced in chemical industry. Often the glycerine is secondary product of the main production process and it is treated as the waste medium. The idea of glycerine use in HSS for the waste heat accumulation and district heating is presented in fig.3.

Nowadays the possibility of phase changing materials (PCM), such as the hydrated salts, for heat accumulation is being analysed in many scientific units worldwide. The list of possible to use in HSS PCM materials were presented in [6]. Author has presented initial results of his own research in this matter in [7]. Interesting application of HSS based on

PCM for the central heating in Court Centre in Düsseldorf was presented in [8].

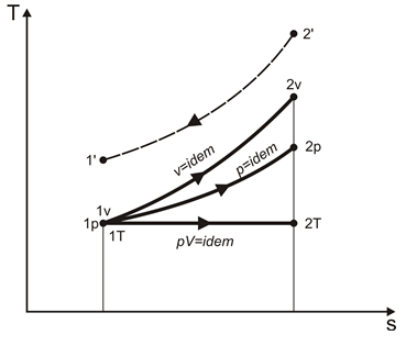

Fig.2. Comparison of other possible heat accumulation processes with isochoric process

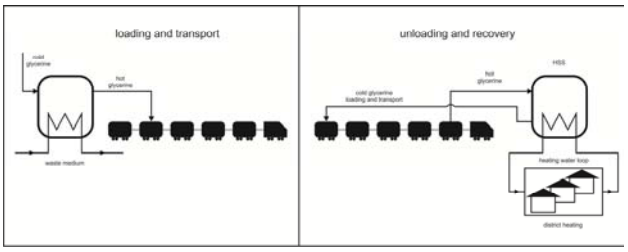

Fig.3. Idea of glycerin use in HSS for the waste heat accumulation and district heating

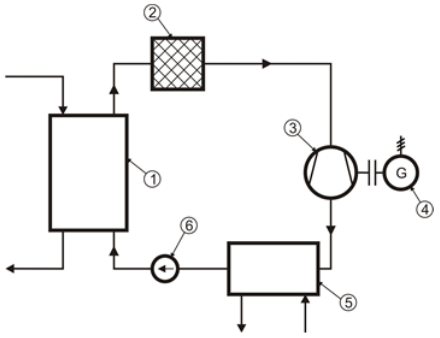

Fig.4. Scheme of the ORC power plant combined with the HSS 1 – vapour generator; 2 – heat accumulator/HSS; 3 – expander; 4 – generator; 5 – condenser; 6 – feeding pump

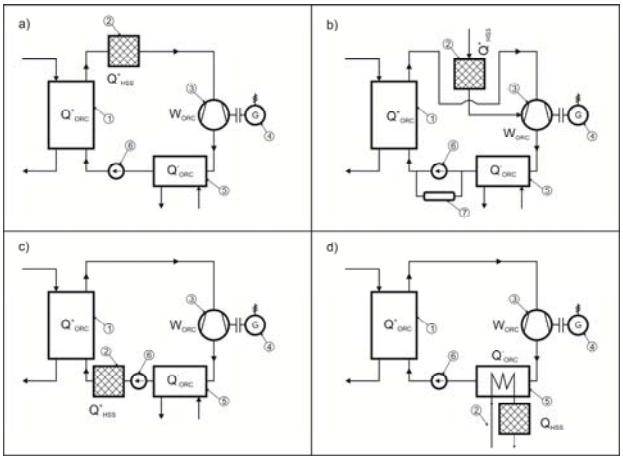

Fig. 5. Different possibilities of the HSS use in the ORC systems a) stabilization of the heat source characteristic; b) ensure of the additional vapour inlet to the expander; c) preheating of working substance; d) assist in CHP 1 – vapour generator; 2 – heat accumulator/HSS; 3 – expander; 4 – generator; 5 – condenser; 6 – feeding pump; 7 – working medium reservoir

The Analysis of Possibility of Heat Accumulators and HSS Use in the ORC Power Plant Powered by the Heat Source with Changeable Characteristic

Use of the heat accumulator or HSS in ORC power plant powered by the heat source with changeable characteristic can have following purposes:
- modulation of the energy source characteristic in order to its stabilization and improvement of the ORC system work conditions,
- initial heating of the working medium,
- provision of the reserve energy source in case of momentary decay of the main energy source,
- assist in the CHP realization,
- raise of the system efficiency,
- ensure of the additional vapour inlet to the expander.

In fig.4 the ORC power plant combined with the HSS is presented, in Fig. 5 the different possibilities of the HSS use in the ORC systems are presented.

Modulation of the heat source characteristic

In fig.6 the changeable capacity characteristic of vapour obtained with use of dynamic energy source is presented. As it can be observed the vapour generator working with this source has dynamic changeable and momentary nearly decayed characteristic. In fig.7 the same characteristic but combined with capacity characteristic of vapour obtained from HSS is presented. HSS is modulating the changeable vapour generator capacity in such a way that total vapour amount characteristic is nearly stable.

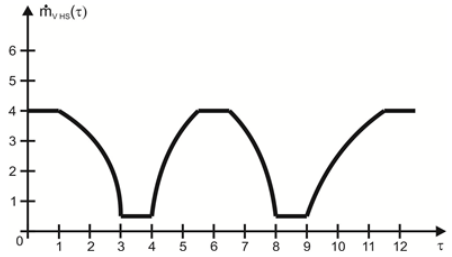

Fig.6. Changeable capacity characeristic of vapour obtained with use of dynamic energy source

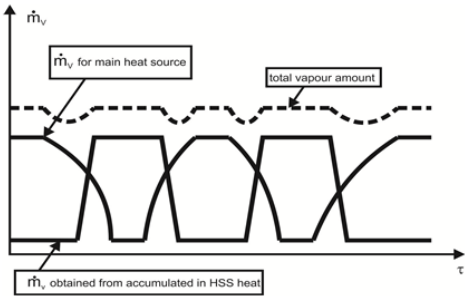

Fig.7. Modulation of changeable vapour generator capacity characteristic with use of HSS

The modulation of changeable vapour generator capacity characteristic can be realized with use of the system presented In fig.5a. The efficiency of this system can be calculated from the following equation:

$$\eta_{\text{ORC\_HSS}} = \frac{W_{\text{ORC}}}{Q_{\text{ORC}} + Q_{\text{HSS}}} \tag{2}$$

where: W_{ORC} – work done in the expander, Q_{ORC} – heat transferred to the working medium in the evaporator, Q_{HSS} – heat transferred to the working medium in the HSS.

Ensure of additional vapour inlet to the expander

Such solution would be helpful for use of the energy collected in additional flux of vapour, transferred directly to

the expander inlet. Additional flux of working medium can be supplied from other modules if the module system formed by different subassemblies with different technical tasks is being considered.

Such solution can be realized with use of system presented In fig.5b. The efficiency of this system can be calculated from the following equation:

$$\eta_{\text{ORC\_HSS}} = \frac{W_{\text{ORC}} + W'_{\text{ORC}}}{Q_{\text{ORC}} + Q_{\text{HSS}}} \quad (3)$$

where: W_{ORC} – work done in the first stage of the expander, W'_{ORC} – work done in the second stage of the expander, Q_{ORC} – heat transferred to the working medium in the evaporator, Q_{HSS} – heat transferred to the working medium in the HSS.

Additional flux of working medium (liquid or vapour) is transferred to the HSS where its thermodynamic parameters are raised. Then this medium is transferred to the expander where it is being expanded and additional work is done. Such solution can be helpful also in case of the main energy source decay – the system would be able to continue the operation for some time period. As it results from authors estimations [4] application of the additional vapour inlet to the expander can contribute to raise the efficiency of ORC system by 1-2%.

Initial heating of working medium

The heat collected in the HSS can be used for initial heating of working medium. Use of such solution can be helpful in:
- lowering energy load of main energy source,
- possibility of many energy sources with different temperatures use in system,
- raising of ORC system efficiency.

In fig.5c the construction scheme of ORC power plant with initial heating of working medium provided by HSS is presented. The efficiency of this system can be calculated from the following equation:

$$\eta_{\text{ORC\_HSS}} = \frac{W_{\text{ORC}}}{Q_{\text{ORC}} + Q_{\text{HSS}}} \quad (4)$$

where: W_{ORC} – work done in the expander, Q_{ORC} – heat transferred to the working medium in the evaporator, Q_{HSS} – heat transferred to the working medium in the HSS.

The initial heating of working medium can contribute to raise of the ORC system efficiency by approx. 1% [4].

Assist in CHP realization

The HSS can be also helpful as assist in CHP realization. It can be assumed that the condenser cooling medium is water, which is then used for heating up of the water in central heating system. The heat transferred in the condenser by the ORC system working medium, for the sake of the low range of operation temperatures, can be insufficient for ensure of needed raise of heated medium temperature. In this purpose the HSS can be used in order to heat up the water to the needed temperature. In fig. 5d the construction scheme of ORC power plant with HSS used for heating up the central heating water is presented. The efficiency of this system can be calculated from the following equation:

$$\eta_{\text{ORC\_HSS}} = \frac{W_{\text{ORC}} + Q_{\text{CHP}}}{Q_{\text{ORC}} + Q_{\text{HSS}}} \quad (5)$$

where: W_{ORC} – work done in the expander, Q_{CHP} – generated heat, Q_{ORC} – heat transferred to the working medium in the evaporator, Q_{HSS} – heat transferred to the working medium in the HSS.

The application of HSS for warming up of the central heating water can contribute to raise of the ORC system efficiency by 3 - 4% [4].

Summary and Conclusions

Presented in paper proposals of HSS use in ORC power systems can contribute to:
- raise in renewable and waste energy sources use,
- raise of efficiency of different energy forms generation in ORC systems,
- decentralization of energy supply system,
- raise of energy safety,
- development of regional energetic systems and Autonomous Energy Regions described in [9], [10] and [11],
- use of local energy sources with low potentials.

At present author is working on design of test set-up of hybrid ORC-HSS system. The system will be powered by the low thermal potential heat source. R1234ze is considered as a working fluid. The HSS will be specially constructed with use of honeycomb shape cooper plates. Specially shaped working fluid flow channels will enable the possibility of carrying out a wide range of experiments. In particular the following research analyses will be carried out:
- influence of the heat transfer processes in HSS for the changeable heat source characteristic modulation,
- influence of the additional vapour inlet to the expander on the ORC system efficiency,
- influence of the heat transfer processes in HSS on the hybrid ORC-CHP system efficiency.

Initially, during the tests, the HSS will be loaded with help of the electric heaters. During the research analysis it will be loaded from the real waste heat source. The design and construction of the HSS prototype is the subject of currently prepared patent application.

REFERENCES

[1] Praca zbiorowa, Przemysłowa energia odpadowa: zasady wykorzystania; urządzenia, *WNT Warszawa* (1993).
[2] Gnutek Z., Kolasiński P., Lamperski J., Odzysk ciepła z odpadowych źródeł energii, Materiały XIII Sympozjum Wymiany Ciepła i Masy, Tom 1, pod red. H. Chauna, *Wydawnictwa Uczelniane Politechniki Koszalińskiej*, (2007).
[3] Ochęduszko S., Teoria maszyn cieplnych cz. III, *PWT*, (1955).
[4] Kolasiński P., Termodynamika układów konwersji energii o zmiennej ilości czynnika roboczego, Praca doktorska, *Politechnika Wrocławska*, Wrocław (2010).
[5] Domański R., Magazynowanie energii cieplnej, *PWN*, (1990).
[6] Agyenim F., Hewitt N., Eames P., Smyth M., A review of materials, heat transfer and phase change problem formulation for latent heat thermal energy storage systems (LHTESS), *Renewable and Sustainable Energy Reviews* vol. 10, (2010).
[7] Kolasiński P., Zawadzka E., Wstępna analiza możliwości wykorzystania roztworów przesyconych do pozyskiwania ciepła ze źródeł alternatywnych o niskich potencjałach, Materiały XIV Sympozjum Wymiany Ciepła i Masy, *Wydawnictwo Politechniki Szczecińskiej*, Szczecin (2010).
[8] Kuczia P., Wielkogabarytowy gruntowy wymiennik ciepła w korelacji z centralnym zasobnikiem ciepła z materiałów zmiennofazowych PCM w Centrum Sądowym w Düsseldorfie - studium przypadku, *Instal nr.3 rocznik 2012,* Warszawa (2012).
[9] Gnutek Z., Kolasiński P., Struktura energetyczna Dolnego Śląska – zagadnienia wybrane*, Cieplne Maszyny Przepływowe – Turbomachinery* nr 132, Wyd. Politechniki Łódzkiej, (2007).
[10] Gnutek Z., Analiza w obszarze potencjału rozwojowego regionu: Cz.5. Analiza potencjału rozwojowego regionu w dziedzinie energii odnawialnych i alternatywnych, *Raport I-20*, Wrocław (2007).
[11] Gnutek Z., Autonomiczne regiony energetyczne sposobem na racjonalizację wykorzystania odpadowych i odnawialnych źródeł energii, Przyszłość energii odnawialnej – polityka energetyczna, trendy, *Materiały I Dolnośląskiego Forum Energii Odnawialnej*, Wrocław (2007).

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