EXPERIMENTAL STUDIES ON LOW POWER ORC`s WITH VANE EXPANDERS

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INTRODUCTION

Nowadays an large increase in interest in use of alternative energy sources can be observed. Such tendency applies to renewable as well as waste resources. Therefore many modern and innovative energy conversion technologies has occurred on the market on last few decades. Among them we can find: fuel cells, solar collectors, wind power plants, etc. One of the most interesting alternative energy conversion technology is ORC, which is useful for conversion of low-quality energy (for example waste heat) in a high-quality energy (electricity). ORC systems, in spite of the same operating rules can be different in technical architecture. Chosen technology is dependent from system power and its purpose. Research studies on ORC`s are carried out for many years in a large number of scientific units and companies worldwide.

A long tradition in research on such systems has the scientific team of Department of Thermodynamics – the part of Institute of Power Engineering and Fluid Mechanics at Wrocław University of Technology. In Department of Thermodynamics, from nearly 20 years, study and experimental works on application of rotary expanders in ORC`s are carried out. Research team has been awarded by 2 grants in this subject from Polish Ministry of Science and Higher Education.

3 scientific monographs: 1 habilitation [1], 2 doctorates [2], [3] and a large number of scientific articles has been dedicated to ORC`s. Two prototype test stands with rotary vane expanders has been set up.

In this paper authors present the range of carried out works and further scientific plans related to ORC`s.

THEORETICAL AND EXPERIMENTAL WORKS ON ROTARY EXPANDERS

In Department of Thermodynamics research works on ORC`s appeared as an additional subject to studies on refrigeration gas systems with rotary vane expanders. Experiments showed that rotary expanders have interesting property of the optimum degree of expansion due to power, with a value of σ_r = 2.8-3.2. Expander operating speed is 1500-4000 rpm, and construction is not technically difficult. Typical machine power is 0,2-2 kW with possibility of raise to few kW.

The theory of rotary machines was described by Zbigniew Gnutek in the monograph entitled "Rotary vane machines" [1]. First experimental ORC was set up with use of pneumatic engine from grinder. Theoretical analyses on ORC`s were done by team in the period of intensive search for new working mediums. Especially for heat sources with unstable characteristics. At that time R11, R12, etc. were used in ORC`s but were simultaneously withdrawal of use, due to large impact on the environment. Among the new proposals of working mediums was a large set of substances with quite different thermodynamic properties. Therefore research subject on the working mediums was started by a team. The main objective of this research was the proper working medium and ORC parameters selection for chosen waste heat source in order to achieve the maximum system power. The method of proper medium selection was described in [4] and [5] and then developed in [3]. As a result of method applying ORC thermodynamic parameters, construction and components, including expanders, were selected. It was found that in the real cycles degree of expansion can get different values $\sigma_r > 3$ or $\sigma_r < 2.8$. Therefore construction of multistage and parallel expanders with various construction parameters [6] was proposed. Such systems are suitable especially for waste heat sources with unstable characteristic and multicomponent systems mounted on one shaft.

FIRST ORC PROTOTYPE

First experimental ORC in Department of Thermodynamics was set up in 1994. Research team formed by: Zbigniew Gnutek, Grzegorz Lange and Andrzej Stefanicki, worked under direction of Prof. Eugeniusz Kalinowski, and used the experience acquired from eelier works in scope of rotary machines. Test stand was set up in the framework of grant No. 901199101 awarded to authors by Polish Ministry of Science and Higher Education.

It was also the first ORC in Poland with rotary vane expander. System were constructed from following main components: evaporator (designed in the form of a container with an internal copper steam coil, whole covered with liquid), vane expander with generator, vane pump with electric motor, shell-tube condenser, liquid reservoir and measuring system.

Liquid in evaporator was heated up with electric heaters. View of this evaporator is presented on fig. 1. Working medium has been transferred from horizontal reservoir to evaporator by a vane pump. View of pump with motor is presented on fig. 2. Vapor from evaporator was flowing through pipelines to vane expander interconnected by clutch with power generator (automotive alternator). Expander with power generator is presented on fig. 3. After expansion working medium was flowing through pipelines to tube-shell condenser cooled with cold water. After condensation liquid was flowing to reservoir. Generated electricity was consumed by electric devices connected with a set of power measuring equipment. View of test stand is presented on fig. 4 and 5.

After construction works ORC was tested with a series of experiments, carried out by Stanisław Biernacki in the framework of his PhD thesis. During first test series evaporator container was filled up with water. R11 was chosen as a working medium. After a series of experiments and analysis of results, it was decided to optimize system construction. Most important changes included insulation of pipelines and replacement of evaporator liquid by thermal oil. On modernized ORC a series of experiments were carried out, and results were used by Stanisław Bierncaki to complete his PhD thesis. One of his postulates was necessity of change of low boiling working medium.

Fig. 1. View of evaporator

Fig. 2. View of pump

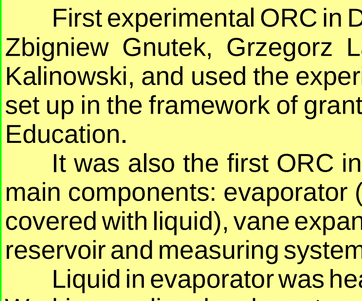

Fig. 3. View of expander

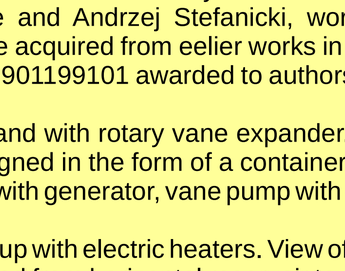

Fig. 4. View of test stand

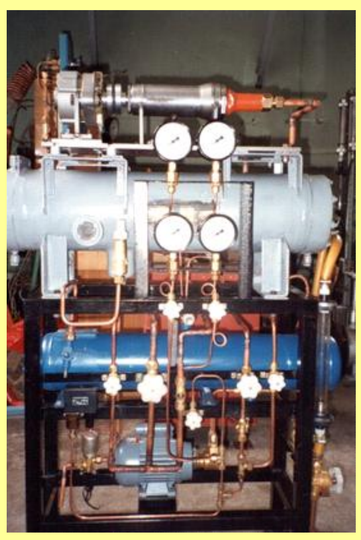

Fig. 5. View of test stand

SECOND ORC PROTOTYPE

Second ORC test stand was set up in Department of Thermodynamics in 2009. Main research goal was to examine practical possibilities of use of waste heat sources to cover energy needs in a stand-alone object with low power needs. Research was mainly related to waste heat sources with unstable characteristics, and combined heat and power generation. Prototype was created in framework of grant No. 3T10B04629 awarded by the Ministry of Science and Higher Education and PhD thesis by Piotr Kolasiński.

Construction works were carried out in two stages. Each stage was dedicated to different research priorities. View of the system is presented on fig. 6.

Test stand is constructed from following main components: gas central heating boiler with a closed combustion chamber, shell-tube evaporator, two vane expanders, working medium reservoir, plate condenser, vane pump with motor and measuring system. The working medium is R123. Test stand is hermetic, modular CHP system that can be easily modified.

It was designed and constructed in order to carry out analyses of:

- possibility of use of commonly occurring unstable waste heat sources with low potentials for generation of power in ORC`s,
- applicability of different types of expanders for use in ORC`s,
- influence of variable amount of working medium in cycle on efficiency and thermodynamic parameters of ORC`s,
- influence of the working medium type for ORC thermodynamic and technical parameters,
- heat and mass transfer processes in system components,
- multi-cycle modular ORC systems.

The prototype was set up with use of serial, available on the market components. It was decided to apply vane expanders, usually used as compressors or engines.

First research stage was dedicated to examination of practical possibilities of use of waste heat sources to cover energy needs in a stand-alone object with low power needs. Waste heat recovery was done directly from gas boiler flue gases, which were directed through chimney and a valve system to the shell of evaporator. R123 was pumped by pipelines to the convective bunch of evaporator. Vapor with high thermodynamic parameters was flowing through two vane expanders (1.5 kW each). Both expanders were interconnected by magnetic clutches with generators. After expansion vapor was condensed in plate condenser cooled by cold water. On fig. 7 view of expanders with magnetic clutches is presented.

Fig. 6. View of test stand

Fig. 7. View of expanders with magnetic clutches

For second research stage test stand was modified in order to wideness of measuring range. First modification was the change of heat source. It was decided to use the hot central heating water from boiler. Such solution lowered the heat source temperature, but it gave the possibility of wide temperature adjustment and simulate other waste and renewable heat sources. Second modification was the change of expanders. Miniature vane expanders (330 W each) were installed on test stand in order to analyze the possibility of system miniaturization. On fig. 8 views of chosen system components are presented.

Hot central heating water was directed by pipelines to shell of evaporator. Specially designed valve system gave the possibility of parallel and counter flow of mediums. R123 was pumped by pipelines to the convective bunch of evaporator. Vapor with high thermodynamic parameters was driving two vane expanders.

Fig. 8. Views of chosen system components

Experiments done in the first and second research stage shown that it is possible to use unstable heat sources with low potentials as the heat sources for domestic micro ORC systems. The analysis also showed that it is possible to miniaturize system by applying the miniature vane expanders.

SUMMARY

Within the framework of the research works carried out over a period of nearly 20 years 2 working ORC prototypes with vane expanders were set up. In the result of theoretical and experimental research have been developed:

- method for a working medium selection to the chosen waste heat source,
- method for an optimum expander selection to the ORC with a specific working medium and powered by the heat source with known characteristic,
- thermodynamic characteristic of potential ORC working mediums with a set of new assessment parameters,
- description of waste heat sources with new parameters including: heat source temperature stability coefficient, heat source mass flux stability coefficient, heat source efficiency use coefficient, heat source usability coefficient,
- new assessment parameter – energy efficiency coefficient,
- the method of ORC systems assessment (in many technical configurations) with use of energy efficiency coefficient,
- new technical configurations of ORC systems with cascade expanders systems,
- analysis of ORC`s work conditions in case of multi heat source powering.

Also authors with a team of Department of Thermodynamics are currently analyzing:

- the design and construction of multistage volumetric expanders,
- new small power domestic ORC prototype waste heat powered,
- project of solar energy self-sufficient house with ORC system.

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