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Selected theoretical and practical investigations and optimization issues of Organic Rankine Cycle applied for waste heat recovery

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Abstract

One of the comprehensive practical application areas of the Organic Rankine Cycle is heat recovery from different low and middle temperature “waste heat” sources. Relating to this, the paper presents some important theoretical optimization issues and results of the practical investigation carried out during the testing of the ORC plant using a screw engine as an expansion device. The selection of suitable organic fluids for application in the Organic Rankine Cycle was a crucial step to achieve high thermal efficiency. In a previous study, a special tool was developed in order to compare the influence of different working fluids on the performance of an ORC heat recovery power plant installation. The tool chooses an optimal working fluid for special applications and becomes a part of a bigger optimization procedure applicable at different boundary conditions. The second optimization issue is minimization of exergy losses between the heat source and the cycle, through the use of special optimization procedures that not only select the working fluids, but also evaluate the possible types of processes under consideration of given boundary conditions and limitations. Based on these theoretical considerations, and in accordance with practical requirement, a special ORC test and demonstration plant has been developed and installed, especially for “waste heat” utilization from exhaust gas and cooling water of biogas installations. The biggest practical solution and challenge was the application of the screw engine as the expansion machine. At the end, certain representative measurement results are presented in order to illustrate some practical possibilities and limitations of the tested installation as well as compare them with theoretical assumptions.

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Keywords: ORC; low temperatur; middle temperatur; waste heat; biogas

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1. Introduction

Organic Rankine Cycle (ORC) power plants applied in various energy supply systems are some of the most effective measures for efficiency enhancement of existing installations and allowing energy extraction from previously unsuitable sources. Applications based on this cycle allow the use of low and middle temperature and enthalpy sources such as waste heat from industrial applications, geothermal sources, biomass fired power plants, combined heat and power systems, and others. The ORC system exhibits great flexibility, high safety, and low maintenance requirements for recovering this grade of waste heat. By integrating the ORC into the energy system, one could have the ability to use low grade energy to generate high grade energy, thereby lowering the power burden and enhancing system efficiency. Since the ORC consumes virtually no additional fuel for the same added power, the emission of environmental pollutants such as carbon dioxide, sulphur dioxide, and others would be decreased. Additionally, according to the local demand, the exhaust condensation heat exiting from the ORC could be further utilized to drive chillers, such as absorption chillers, to supply cooling capacity [1].

J. Bao and L. Zhao summarized and reviewed in their article the most important aspects and information related to the theoretical and practical use of ORC-Installations, such as working fluids and their thermodynamic and physical properties (pure and mixed working fluids), limitation of working fluid selection, expansion machines, as well as knowledge gaps and development direction [2].

In this way, selective targeted continuation and research works are necessary to develop new possibilities and to optimize the existing ones. This means both the theoretical research work – for example thermodynamic optimization and minimization of exergy losses -- as well as practical investigations and tests such as the development of new expansion devices, mixed working fluids, and the testing and evaluation of operational experiences.

Nomenclature

$\dot{Q}_{in}$	heat flux input	[W]
$\dot{m}$	mass flow rate	[kg·s ⁻¹]
v	specific volume	[m ³ ·kg ⁻¹]
h_i	specific enthalpy for process point i	[kJ·kg ⁻¹]
T_{high}	high system temperature	[K]
T_{low}	low system temperature	[K]
p_{high}	high system pressure	[Pa]
p_{low}	low system pressure	[Pa]
$\eta_{turbine}$	internal efficiency of the turbine	
η_{pump}	internal efficiency of the pump	
η_{system}	system efficiency	
P_{pump}	power used by the pump	[W]
$P_{turbine}$	output power of the turbine	[W]
$\dot{Q}_{out}$	heat flux output in the condenser	[W]

2. Selected optimization issues related to working fluids and installation types

Working fluid selection is a major step in designing heat recovery systems based on the Organic Rankine Cycle as presented and analyzed in numerous publications, for example [2,3,4,5]. As a result of our own theoretical investigations and comparative analysis, a special calculation and optimization procedure and program has been developed, which facilitates working fluid selection, calculations for different types of installations and some additional tasks [6,7]. The characteristics of the fluids have been sorted in two major groups, each containing multiple parameters: thermo-physical characteristics and environmental characteristics. The database has been assembled in MS Excel due to the wide-spread use of the program and the fact that it facilitates the structuring and organization of data sets in an easy and intuitive way.

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