DYNAMIC MODELING OF WASTE HEAT RECOVERY ORGANIC RANKINE CYCLE SYSTEMS IN THE AMESIM PLATFROM

L. Guillaume[a], B. Ameel[b], C. Criens[c], I. Siera[c], D. Maes[c], A. Hernandez[d], M. De Paepe[b,c], V. Lemort[a]

[a] Department of A&M, Thermodynamics laboratory, University of Liege, Belgium
[b] Department of Flow, heat and combustion mechanics, Ghent University, Belgium
[c] Flanders Make, Lommel, Belgium
[d] Department of Electrical energy, Systems and Automation, Ghent University, Belgium

e-mail: ludovic.guillaume@ulg.ac.be
Web page: www.labothap.eu

Highlights: A methodology for dynamic modeling in the LMS AMESim platform is proposed. 12 topologies of Organic Rankine Cycle systems are investigated. The model parameters required in AMESim are automatically propagated from steady-state models. Experimental data is used to validate the models and the methodology.

Key words: ORC, WHR, Heavy-duty trucks, Dynamic simulations, LMS AMESim.

EXTENDED ABSTRACT

Introduction

ORC waste heat recovery is a very promising technology for reducing fuel consumption and consequently the CO2 emissions of future heavy-duty trucks. Because of the transient nature of the heat sources encountered on a truck, dynamic simulations are an essential part of the design process of ORC systems for truck applications. Dynamic models are useful for component design, control design and transient evaluation of ORC systems.

To ease the burden of building numerous dynamic models of different candidate ORCs while the design process is ongoing, a library of generic dynamic models of ORCs is built in this work. These models work in synergy with a steady-state ORC design tool in which is added a function to automatically populate the parameters of the dynamic models.

In this work, the dynamic model library and their parameterization process in LMS AMESim are described. The platform is largely used in automotive industry and offers a variety of libraries: Engine, Control, Two-Phase Flow, etc.

Finally, the dynamic models are compared against the steady-state models and experimental data.

Description of the models

1. Topologies: Two heat sources are investigated: the exhaust gases and the recirculated exhaust gases. Combining these sources, 6 possible configurations are identified (2x1 heat source, 3x2 heat sources in serial, 1x2 heat sources in parallel). On the other hand, the engine cooling fluid is considered as the single heat sink. Including the use (or not) of a recuperator, this leads to 12 topologies.

2. Heat exchanger models: In order to accurately predict the heat exchange but also the temperature profiles of the two fluids going through one heat exchanger, the finite volume approach is selected for modeling. The Two-phase flow library is used on the working fluid side while the pneumatic library and the thermal hydraulic library are used on the exhaust gases and the cooling water sides respectively.
3. Expansion machine and pump models: For both components, the displacement and the evolution of the isentropic and volumetric efficiencies with operating parameters are set.

Parameters Definition And Comparison Against Steady-State Models

To facilitate the parameterization process and to validate the dynamic models against the steady-state model, an interface has been developed in Matlab.

For the heat exchangers, the steady-state model consists of a detailed analysis incorporating the refrigerant circuiting and detailed geometry-based correlations for the heat transfer coefficients on refrigerant and secondary fluid sides. The dynamic model on the other hand consists of a counterflow heat exchanger with a simple Dittus-Boelter type Nusselt correlation for the secondary fluid side and correlations for flow in a circular tube on refrigerant side. As both models use a fundamentally different set of parameters, a transformation from the steady-state model parameters to the dynamic model parameters is required. This transformation ensures that the steady-state and the dynamic model predict the same steady-state behaviour for a variety of different working conditions.

Comparison Against Experimental Data

Validation of the dynamic behaviour of the ORC models requires experimental data. Because data from waste heat recovery from exhaust gases is not available at this stage of the study, it is proposed to validate the methodology and the model using measurements achieved on a small scale ORC unit which is using thermal oil as heat source and R245fa as working fluid.

Conclusion

A good agreement is observed when comparing the dynamic models of the ORC system against the steady-state models. For instance, a maximal offset of 2K can be achieved on the temperature of the working fluid at the exhaust of the evaporator for a variety of input conditions (Figure 1). A good agreement is also observed when comparing the dynamic behaviour of the model against experimental data (Figure 2). During the experiment, the working fluid mass flow rate (blue) and the oil temperature (black) were increased in order to increase the evaporating pressure while keeping a constant overheating. A maximal difference of 1K is observed between the measured (green) and the predicted (red) evaporator outlet temperatures.

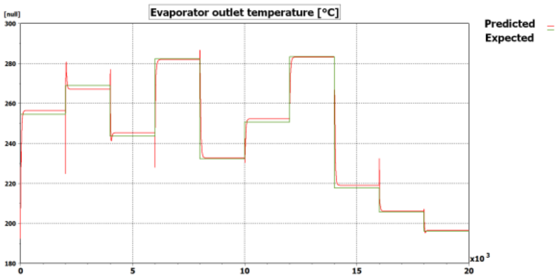

Figure 1: Example of comparison against steady-state model for an evaporator using ethanol.

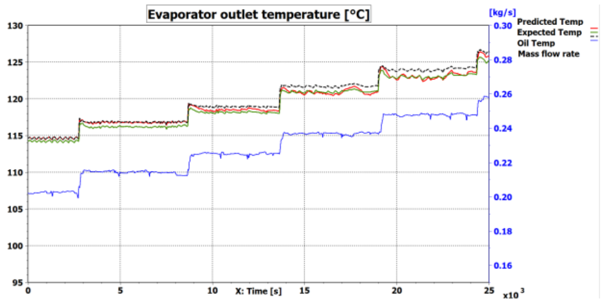

Figure 2: Validation of the methodology using experimental data

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Background of the research and development team

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Authors

Ludovic Guillaume obtained his MSc (electromechanical engineering) at University of Liege where he is working now as a PhD student within the Energy Systems Research Group (Thermodynamics Laboratory). He has been working on waste heat recovery from engines since 2011, in collaboration with Industry and in the frame of public funded projects (FP7 Nowaste project).

Bernd Ameel is a postdoctoral researcher at the Department of Flow, Heat and Combustion Mechanics, Ghent University, Belgium. He obtained his Ph.D. from Ghent University in 2014 and his master's degree in electromechanical engineering from the same university in 2010. His main research interest is the numerical optimization of compact heat exchangers.

Chris Criens obtained his MSc (control systems technology) and PhD (air-path control of clean diesel engines) at Eindhoven University of Technology. He is currently working at Flanders Make, where he works on model based design of ORC waste heat recovery systems and hybrid drivetrains.

Ilja Siera obtained a BsC in aeronautics at Haarlem UoT, The Netherlands and a PhD at Imperial College London (Optical characterisation of coal fired flames for the reduction of emissions). He is a senior research engineer at Flanders Make in the domain of clean and energy efficient vehicles.

Davy Maes obtained his MSc (electronics-ICT) at KH Kempen. He is currently working as a project manager at Flanders Make where he is leading research projects on model-based systems engineering and energy efficient system design.

Andres Hernandez received his B.E (Electronic engineering) and the M.Sc. degree (Control Engineering) from University of Ibague, Colombia. He is currently Ph.D. researcher at Ghent University and University of Liege, Belgium, working on the control design for ORC waste heat recovery systems.

Michel De Paepe is professor of thermodynamics in the Faculty of Engineering at Ghent University. He graduated as master of science in electro-mechanical engineering at the Gent University in 1995 and obtained the Ph.D. in electro-mechanical engineering at the Gent University in 1999. He is currently heading the Applied Thermodynamics and Heat Transfer Research Group at the Faculty of Engineering at the Ghent University. His research focuses on thermodynamics of new energy systems, performance of HVAC systems and energy in buildings, and complex heat transfer phenomena in industrial applications, as in compact heat exchangers, refrigerant two-phase flow, and electronics cooling. He has co-authored 100 papers published in international peer-reviewed journals and more than 280 conference papers.

Vincent Lemort is an Assistant Professor at the University of Liège (Belgium), where he is leading the Energy Systems Research Group (Thermodynamics Laboratory). He has been working on waste heat recovery from engines since 2005, in collaboration with Industry and in the frame of public funded projects (FP7 Nowaste project). His team has contributed to the simulation and the testing of many ORC systems and components.