David Tomás Sánchez Martínez
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Proceedings of the 7th International Seminar on ORC Power Systems

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ENHANCING KNOWLEDGE OF ENGINEERING STUDENTS AT ALL LEVELS ON ORGANIC RANKINE CYCLE SYSTEMS FOR THEIR APPLICATION IN THE BUILT ENVIRONMENT

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ABSTRACT

According to International Energy Agency (IEA), the global energy crisis is accelerating the use of renewable energy in the next five years. Furthermore, the building sector which accounts for about 30% of the final energy consumption, has a significant room for improvement in curbing its share of energy consumption and integrating renewable energy technologies. Hence, the 'Skybelt' project, co-funded by the EU under the framework of the Erasmus+ programme and coordinated by eCampus University - Italy, aims at enhancing the skills of engineering students at all levels for application of sustainable renewable energy solutions to be integrated into the built environment in several Asian and European universities.

The market analyses conducted in the initial stage of the project have revealed that combined heating and power (CHP) and combined cooling, heating, and power (CCHP) are the most interesting applications of knowledge for future employees on renewable energy. Among the potential CHP and CCHP technologies, Organic Rankine cycle (ORC) systems are interesting for the building energy sector thanks to their capability to be combined with solar and biomass sources.

Therefore, Universiti Putra Malaysia (UPM), Universiti Sains Malaysia (USM) and Naresuan University (NU) opted to be equipped with non-regenerative ORC test benches for training of engineering students at different levels. In particular, bachelor students at UPM will work on the development of different control approaches on small-scale ORC units within the modernised module of 'Control System Analysis', and students at USM and NU will be trained on the operating performance of these systems to be combined with different renewable energy sources. Hence, the project has given the opportunity to foster knowledge about the ORC systems for engineering students at all levels with the perspective of adopting them in buildings.

1 INTRODUCTION

Buildings are the single largest energy consumer in EU accounting for approximately 40% of the EU energy consumption and 36% of greenhouse gas emissions (European Commission, 2021). In particular, 27% of final energy consumption in 2020 was accounted for households according to Eurostat (2022), of which 62.8% for space heating, 15% for water heating and 0.4% for space cooling that is increasing steadily. Despite these numbers may differ in other regions of the world, the high impact of the building sector in the energy consumption is also significant in Asia and South East.

Furthermore, in the transition towards a more secure and sustainable energy supply, renewable power additions must triple (825 GW of renewables each year until 2050) to reach the average milestones set by the IEA's Net Zero scenario by 2050, and by the World Energy Transitions Outlook scenarios from the IRENA (REN21, 2022).
Such a challenging commitment requires a competent workforce of practitioners and professionals with strong knowledge in renewable energy technologies (RETs). In recent years, the labour market has been pulled by an increasing demand of employment linked to RETs. Fragkos and Paroussos (2018) by investigating the net employment impacts of the EU energy sector transformation towards a renewable energy one, found that this low-carbon transition would reallocate about 1.3% of the EU's workforce across sectors by 2050. Hence, educational curricula incorporating themes related to renewable energy and sustainable livelihood required to be considered in the academic education to deliver trained alumni for such transition. Educating green collar workers to develop and promote renewable energy technologies with technical, professional, and managerial abilities for renewable and sustainable energy sector is among the missions of many university programmes worldwide and is strongly promoted by the EU. In this context, the 'Skybelt' project (2020), co-funded by EU under the framework of the European Union's Erasmus + programme and coordinated by the University eCampus - Italy, aims at enhancing the skills of engineering students at all levels for application of sustainable renewable energy solutions to be integrated into the built environment in several Asian and European universities. All these universities are experiencing an increasing interest in offering up to date and advanced courses on RETs with special focus on those to be integrated in the building energy sector. Furthermore, energy efficiency is another pillar to pursue sustainable development. In the building sector, combined heating and power (CHP) and combined cooling, heating, and power (CCHP) may play a crucial role in curbing CO_2 emissions. Among the possible CHP and CCHP technologies, organic Rankine cycle (ORC) systems have attracted attention thanks to their capability to be combined with geothermal, solar and biomass sources.
In the literature, the use of solar ORC in building sector has been investigated by several authors. For example, Freeman et al. (Freeman et al., 2015) compared different solar technologies in combination with an ORC unit using positive-displacement expander for domestic applications in a typical UK home obtaining 80% of hot water demand coverage and total electrical energy production of 776 kWh/year at best. Rodriguez-Pastor et al. (Rodriguez-Pastor et al., 2023) evaluated the potential of integrating ORC units in existing residential solar thermal installations with findings demonstrating positive economic performances for Mediterranean climate area. Arteconi et al. (Arteconi et al., 2019) investigated the integration of a micro solar ORC plant in residential buildings reporting that the operational strategy and the dynamic energy demand of the building was contributed by 26% from the ORC electricity production. Finally, the use of ORC systems as bottoming units of biomass-based micro-CCHP plants for decentralised trigeneration in buildings has been investigated by a few of the authors of the present paper (Moradi et al., 2023). Therefore, in the context of the 'Skybelt' project, three Asian universities opted to equip their laboratories with non-regenerative ORC test benches for training of their engineering students at different levels with the final aim of promoting the use of ORC systems in buildings.

2 THE SKYBELT PROJECT

The Skybelt project is a cooperation between 3 EU universities in Italy, United Kingdom, and Turkey, and 6 Asian universities in China, Malaysia, and Thailand. More precisely, eCampus University, Northumbria University and Cukurova University from EU countries, Beijing University of Technology, and Lanzhou Jiaotong University from China, Universiti Putra Malaysia (UPM), Universiti of Sains Malaysia (USM) from Malaysia, and Chiang Mai University and Naresuan University (NU) from Thailand.
The modernised teaching methods and contents to be implemented in the 'Skybelt' project were designed based on a student-centred approach having at its focus the satisfaction of the current and future market needs. In this perspective, relevant stakeholders and organisations were interviewed in the early stage of the project to provide feedbacks on the kind of knowledge and expertise the future

engineers should have. More than 120 organisations were identified in Partner Countries of the project and about 110 interviewed. The most relevant results of this survey can be summarised as follows:

- efficiency improvements and reliability and durability of RETs are considered the main challenges to be faced.
- solar energy and heat pumps are considered the main required topics of knowledge of future employees on RETs;
- great interests were expressed for CHP and CCHP systems;
- 11.4% of the interviewed organisations considered ORC technology of interest;
- control and automation, data analysis, and predictive control are the most demanded expertise for future employees.

Further details on the results of this analysis can be found in (Cioccolanti et al., 2021).
Therefore, the outcomes of this survey have driven the selection of modules to be modernised or introduced in Partner Countries universities, as well as the teaching content and methods. Since ORC technology and CHP/CCHP applications are of interest for many stakeholders, UPM, USM, and NU have decided to include the study of ORC systems in the content of some modules and equip their laboratories with a test bench to train their students in this field.

3 THE ORC TEST BENCHES AND THEIR USE

In this section, the driving aspects in the design of the required ORC system test benches and their use at different Asian universities are discussed. In general, the design of these test benches has been based on the experience gained by colleagues at eCampus University in the test of micro-scale ORC systems for waste heat recovery applications (Moradi et al., 2021a). In this case, a 1 kW_{el} non-regenerative ORC unit charged with R134a was developed, making use of the commercial scroll compressor SANDEN TRS090F as expander. Heat is supplied by five electrical heaters (total power input of 22.5 kWe) and provided through silicone oil Texatherm HT22. A chiller that is able to cool the water temperature down to 8°C was used as the heat sink and plate heat exchangers have been selected. Additionally, an oversized piston pump was installed to accommodate testing of different working fluids and types of expanders. Further details can be found in (Moradi et al., 2021b). **451**
Therefore, considering the target applications and the budget constraints, for all three universities, subcritical and non-regenerative ORC configuration was identified as the most appropriate.
With regards to the expansion device, a scroll compressor converted to expander was selected as the common device in many micro-scale ORC systems. Heat is provided using diathermic oil circuit heated by electrical heaters to replicate low temperature applications such as in the case of traditional solar thermal technologies (solar panels and evacuated tubes). Water is used as cooling medium and its heat discharged to the ambient using a chiller.
The main characteristics of the ORC test benches in each Asian university are reported in the following sub-sections together with the analysis to be performed by students within the modernised curricula.

3.1 Universiti Putra Malaysia

At Universiti Putra Malaysia, the test bench has been installed at the premises of the Department of Aerospace Engineering as shown in Figure 1. It consists of the following main components: (i) 500 W scroll expander; (ii) 10 kW electric heater; (iii) plate heat exchanger evaporator and condenser; (iv) 370 W pump. Silicone oil is used to transfer heat generated by the electric heaters to the working fluid (R134a).
The system has been designed to operate with a nominal evaporation temperature of the working fluid equal to 80°C with a maximum superheating temperature up to 100°C. The condenser temperature for the ORC operation is 20-50°C using the cooling water circuit.

Figure 1: Experimental test rig at the premises of Universiti Putra Malaysia

The students are required to demonstrate the operation of the ORC and analyse the amount of electric power produced by the ORC unit with varying heat source temperature. At the end of the experiment, students are able to correlate the performance of the ORC system in terms of expander power output with the heat source temperature and thermal power input. The procedure for this experiment is as follows:

1. Turn on the chiller and set the cooling water temperature at 20°C;
2. Set the oil inlet temperature to evaporator to at least 40°C;
3. Set the oil pump frequency to 40 Hz and turn on the pump;
4. Set the working fluid pump frequency to 50 Hz;
5. Wait for the stabilization of the operating conditions (i.e., the expander inlet temperature and pressure, working fluid mass flow rate);
6. Check if the outlet temperature of the working fluid from the evaporator is higher than the evaporation temperature;
7. Increase the temperature of the heater slowly with a step of 5°C until it reaches 90°C;
8. The ORC starts to operate when all the critical setting of parameters (Step 1 to 7) are fulfilled. The scroll expander starts rotating and the power output is measured at the load bank.

Within the modernised module of ‘Control System Analysis’, bachelor students at UPM will develop real time measurement system for the pressure and temperature of the working fluid at the inlet and outlet of the main components. In particular, the LabVIEW software and NI Compact DAQ 9174 chassis will be used to monitor these parameters. The NI 9203 analogue input module will be used to measure the input current from the pressure transducers and the NI 9211 temperature input module will be used to measure the temperature from the thermocouples. The hardware is shown in Figure 2a. For the pressure measurements, students will use LabVIEW software to convert the measured current to pressure such as shown in Figure 2b.

Based on the measured pressures and temperatures the values of the working fluid thermodynamics properties will be calculated using the open-source library Coolprop and the performance of the main components assessed. In particular, students will be able to evaluate the pump and expander performance in terms of power and isentropic conversion efficiency.

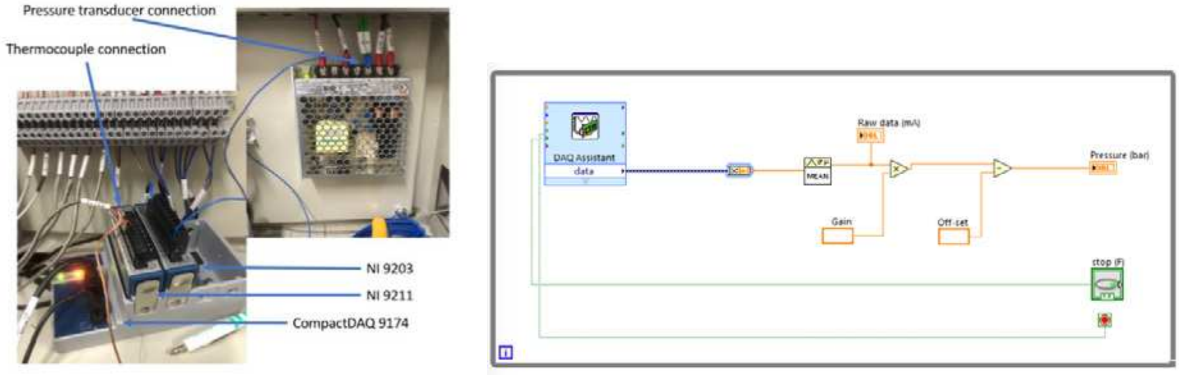

Figure 2: a) Hardware for the data measurement system; b) LabVIEW program for converting current signal to pressure measurement

Furthermore, a more complex experiment will be proposed for the final year project by expanding the function of the data acquisition system. Students will be able to perform a parametric study by changing the variables affecting the outputs of the ORC and design a controller for the ORC system to obtain optimal control of the expander power output. This activity will serve as preliminary study to further improve the present test bench in case additional funds will be available in the future for its upgrade.

3.2 Universiti Sains Malaysia

At Universiti Sains Malaysia, the ORC test bench is installed at the Advanced Renewable Energy Laboratory of the Science and Engineering Research Centre (SERC) as shown in Figure 3. The characteristics of the test bench are the same as the one installed at UPM.

The performance of the ORC unit is assessed in terms of power produced by the expander by changing the electrical load. During the experiments, students will analyse the critical operating parameters such as the evaporation temperature and pressure and the condensing temperature with varying heat source power input and temperature. Furthermore, students will test different working fluids and analyse their impact on the overall system performance.

a) b)

Note:

1. Water Cooler Chiller
2. Condenser
3. Working fluid Pump
4. Expander
5. Generator
6. Liquid Receiver
7. Evaporator
8. Finned Tube Heat Exchanger Tank
9. Control Panel Box
10. Oil Pump
11. Indicators of Temperature and Pressure
12. Control Panel with Switches

Figure 3: Experimental test rig at the premises of Universiti Sains Malaysia (a) ORC piping and connection, (b) Control panel with switches and indicators of temperature and pressure.

The experimental procedure, according to which students at Universiti Sains Malaysia will be trained, is very similar to the one previously discussed for the Universiti Putra Malaysia. However, in this case the laboratory equipment will be used by students attending the selected modernised modules of Internal Combustion Engine and Open-ended laboratory. At Universiti Sains Malaysia, besides renewable energy technologies such as solar thermal panels, the focus is also on the biomass-fuelled internal combustion engines (ICEs) as micro-CCHP units in residential buildings. Hence, the students will be trained on improving the overall energy conversion efficiency of ICEs by recovering the heat of the exhausts in ORC units. Then, the gained expertise could be transferred to other sectors such as industrial applications or transport in which waste heat recovery could improve the primary energy use and reduce the related environmental impact. Therefore, it is expected that students at USM will conduct experiments of ORC operation with different working fluids to investigate its performance for a wide range of low-temperature applications.

3.3 Naresuan University

At Naresuan University, the proof of how low-grade heat can be recovered into useful electric power using Organic Rankine Cycle is performed through the test bench installed at the Department of Mechanical Engineering, Faculty of Engineering. The apparatus is designed to support the teaching on ORC systems at different levels as follows: i) undergraduate students in mechanical engineering will be trained on the operating characteristics of ORC systems; ii) postgraduate students in mechanical engineering will understand the capability of ORC systems in exploiting low-temperature renewable heat sources such as solar by attending some elective modernised modules; and iii) PhD students will conduct experimental investigations using the comprehensive measurement devices and data logging systems. Also in this case, R134a is considered as working fluid and a 500 W scroll compressor is converted to operate as expander. The hermetic scroll expander is connected to a brushless generator with permanent magnets having a maximum DC power of 1500 W at 6000 rpm, high voltage from 200 to 350 V and DC low voltage from 9 to 16 V. Both scroll expander and generator are inside a sealed casing with shell strength of 8.3 MPa on the high-pressure side and 5.2 MPa on the low-pressure side. Compared to the test benches at UPM and USM, this test bench utilises coil heat exchangers for the evaporator and the condenser, and a canned motor centrifugal pump, instead of plate heat exchangers and volumetric-type pump. The low-temperature heat from renewable source is simulated by 12 kW electric heaters and heat is supplied by means of diathermic oil. Water is used as cooling medium at the condenser which, in turn, is cooled down by a dry cooler. The system is designed to operate with nominal evaporating and condensing temperatures of 80°C and 46°C respectively. Figure 4 shows the ORC test rig installed at the Department of Mechanical Engineering of NU.

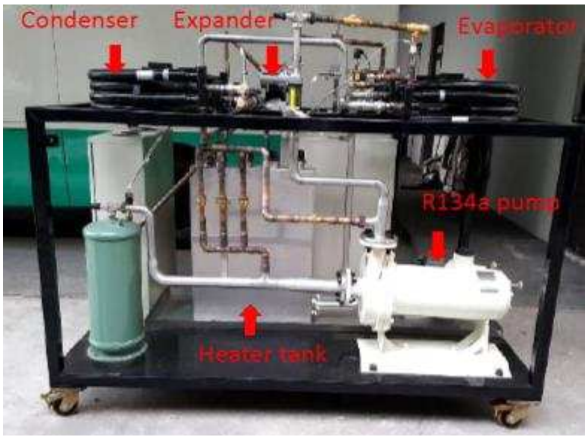

Figure 4: ORC test rig installed at Naresuan University

Pressure transducers having an operating range of 0-40 bar and safety pressure switch are installed at the evaporator inlet and outlet points. Pressure sensors having an operating range of 0-25 bar are installed at condenser inlet and outlet points. Eight thermocouples for measuring the temperature of working fluid, oil, and water are placed at inlet and outlets of condenser and evaporator. A PLC data acquisition and control with LCD touch screen displays real-time operating parameters namely pressure, temperature and flow rate of the fluids together with the power output of the expander.
The data acquisition software is written in LabVIEW and all user inputs and acquired data are monitored. Real time display of temperatures and pressures are available in chart form as shown in Figure 5. This facilitates different training activities such as the recording of the vapor-pressure curve of the cycle, the expander isentropic efficiency and power output, the determination of the heat input and the overall energy conversion efficiency of the system.

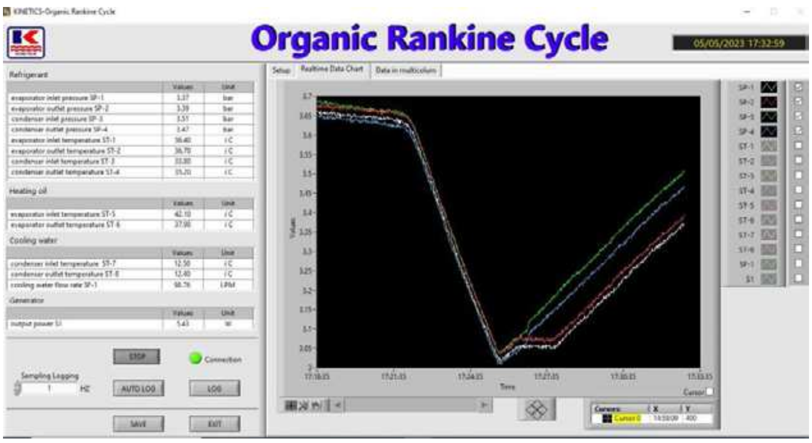

Figure 5: Real-time display of temperatures and pressures by the data acquisition software written in LabVIEW

Students will be trained to operate the ORC system according to the following procedure:

1. Run the oil gear pump which circulates oil between the heater tank and evaporator;
2. Switch on the electric heaters immersed in the heater tank;
3. Switch on the dry cooler;
4. As soon as oil temperature reaches 80°C, switch on the R134a pump. Generator load relays are to be on off-state;
5. When the evaporation pressure of the working fluid reaches 15 bar, open the solenoid valve at the expander inlet;
6. Monitor the superheating degree and subcooling degree and the pressure at evaporator inlet and outlet points;
7. Monitor the shaft speed of the expander;
8. Adjust the generator electrical load as follows: (i) both R1 and R2 relays off (ii) R1 relay on and R2 relay off, and (iii) both R1 and R2 relays on.
9. Adjust heat input by acting on the n°4 electric heaters.

In case of failures, the implemented safety procedure switches off the R134a pump to stop R134a flowing into the evaporator and opens the solenoid valve to release pressure in the evaporator side.
At Naresuan University this laboratory equipment will be used by master students attending the modernised module of Renewable Energy Resources where solar thermal energy is the subject of other modules included in the overall modernisation. In this module, students will simulate the combination of traditional solar thermal panels and evacuated tubes with ORC system for the provision of heating and power to domestic users. The final aim is to assess the performance of such technology with varying ambient conditions and users' needs.

4 CONCLUSIONS

Within the context of 'Skybelt' project, co-funded by the EU under the framework of the Erasmus+ programme and coordinated by eCampus University - Italy, three Asian universities equipped their laboratories with ORC test benches to train their students at different levels on the topic of ORC systems. These universities are Universiti Putra Malaysia, Universiti Sains Malaysia, and Naresuan University. 456
All the ORC test benches are based on subcritical and non-regenerative ORC units using converted scroll compressor as the expander following the experience gained at eCampus University. Electrical heaters are used to supply heat using a diathermic oil circuit and chilled water is used as cooling medium. The ORC systems have been designed to exploit low-temperature heat sources as renewables sources like solar thermal to promote their integration in building for CHP and CCHP applications.
Students will use the test benches in different modules at Partner Countries Universities with the aim of fostering knowledge and providing expertise in the control and operation of such systems for applications in buildings.

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This book contains the compilation of works contributed to the *7th International Seminar on Organic Rankine Cycle Power Systems* (ORC 2023), held in Seville between the 4th and 6th of September 2023. The event was hosted by Universidad de Sevilla on behalf of the Knowledge Centre on Organic Rankine Cycle Technology (KCORC), incorporated in The Netherlands.

The ORC conference, organized biennially, stems as the only conference that is specific to ORC technology, therefore gathering a diverse community whose affiliation spans across all the interested stakeholders, not only in this particular technology but also and in a broader context, in the energy transition. Original equipment manufacturers, professional associations, end-users, investors, policy makers, academics, scientists feel at home at ORC 2023.

The almost 100 proceedings in this book cover a wide variety of topics, from fundamentals to system integration through component design, accounting for thermodynamic performance as well as component design. In addition to this, and as a new track in 2023, works on heat pump technology were also accepted in order to raise awareness of the strong ties between both technologies, specifically in energy storage applications.

This book provides an excellent overview of the current maturity of power systems based on Organic Rankine Cycle technology for applications as diverse as geothermal and waste heat recovery in industry or downstream of other prime movers (e.g., marine applications). It is also an excellent source of information to understand the current challenges faced by the technology, stemming from a very competitive market and increasingly stringent environmental regulations.

The organizers of ORC 2023 hope that the reader finds this work as exciting as the attendees to the conference and, maybe, make the decision to join the 8th edition to the conference in 2025.

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