Micro-scale ORC-based combined heat and power system using a novel scroll expander

Muhyiddine Jradi*, **Jinxing Li, Hao Liu and Saffa Riffat**

Department of Architecture and Built Environment, Faculty of Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, UK

Abstract

Micro-combined heat and power generation (micro-CHP) based on the organic Rankine cycle (ORC) is a flexible technology that allows saving the environment and promoting the economic growth. However, ORC expanders employed recently suffer from key problems including excessive fluid leakage, thermal losses and low isentropic efficiency, and no commercial micro-scale expanders are available in the market and applicable for ORC applications. The possibility of driving a micro-CHP system by solar thermal energy, biomass combustion, waste heat or other clean energy sources allows attaining diversity and security in energy supply as well as decreasing pollutants and gas emissions. In the current work, a solar-biomass-driven micro-CHP system based on the ORC technology is theoretically and experimentally investigated to provide the thermal and electrical needs for residential applications. The micro-CHP system employs an innovative micro-expander utilizing an environmentally friendly working fluid. A numerical model was developed using the Engineering Equation Solver (EES) software to simulate the thermal and electrical performance of the overall CHP system. A parametric study was conducted to investigate the effect of different operational parameters on the CHP system performance. In addition, an experimental set-up was built to test micro-scale ORC-CHP system performance under different conditions using hydrofluoroether (HFE)-7100 fluid. The maximum electric power generated by the expander was in the range of 500 W under a pressure differential of ~4.5 bars. The expander isentropic efficiency has exceeded 80% at its peak operating conditions with no working fluid leakage.

Keywords: combined heat and power; solar energy; biomass heat; organic Rankine cycle; scroll expander

* Corresponding author.
laxmj5@nottingham.ac.uk

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1 INTRODUCTION

In the last two decades, the world primary energy demand has increased due to the technological and industrial development and the tremendous population growth. The total primary energy consumption has drastically increased with a progressive rise in the conventional resources prices, mainly petroleum products. The consumption of such conventional energy resources (gas, oil, coal, etc.) contributes to a large portion of the world greenhouse gas emissions leading to the global warming problem. The conventional energy resources prices increase along with the imminent energy shortage, and the global warming problem has urged the change in energy production and consumption patterns and the switch towards alternative and renewable energy resources (solar, hydro, biomass, wind and geothermal). This switch towards renewables and highly efficient means of energy production will allow flourishing the economic growth, fostering the rural development and saving the environment.

Combined heat and power (CHP) generation system is a flexible technology that allows the simultaneous production of heat and power in the same process offering high reliability with the possibility of being driven by alternative and clean renewable energy resources including biomass combustion heat, solar thermal energy and low-grade waste heat. Using CHP systems for electricity and heat production for both industrial and residential applications is very cost-effective and can save up to 35% of the primary energy generated compared with conventional heat and power systems [1]. A framework for the development of highly efficient CHP generation systems was provided in the European Directive 2004/8/EC in order to attain primary savings in the internal energy market [2]. The total CHP systems capacity installed in the EU has exceeded 100 GW where Germany is leading with 22% of the EU overall capacity followed

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by Poland and Denmark with 9%. Moreover, 46% of the electricity generation in Denmark is provided by CHP systems with 30% in each of Latvia, Finland and Netherlands [3]. On the other hand, the good quality installed CHP capacity in the UK has increased from 5614 MW in 2009 to ~6111 MW at the end of 2011 with medium-scale CHP systems with capacity ranging between 100 kW and 1 MW dominating the market. Figure 1 presents the progressive increase in the installed CHP capacity in the UK in the recent 15 years [3]. In addition, 68% of the CHP systems installed in the UK run using natural gas, where the share of renewable energy-driven CHP systems was only 6% of the total installed capacity in 2010.

A comprehensive review for the recent developments in the field of micro-CHP systems was presented by Jradi *et al.* [4]. Different prime movers with various technologies can be considered for micro-CHP applications. Some of the technologies are commercially available such as reciprocating and micro-turbine engines, whereas others are still in the research and development phase including organic Rankine cycle (ORC) units and fuel cell-based systems. Stirling and Rankine units are the two most favourable and feasible technologies for micro-CHP systems in buildings driven by renewable energy resources due to their flexibility, low emissions and acceptable efficiencies. However, Stirling engines need high-quality heat, which is accompanied by high investment costs. Thus, Rankine-based micro-CHP units provide an effective technology to supply heat and electricity for residential applications with an acceptable efficiency. Utilizing the same technology as the ordinary steam-based Rankine units, ORC-based micro-CHP systems employ organic working fluids as the main driver instead of water. They have received an increasing attention in the recent years in the field of micro-scale power generation and heating in residential and building applications with various advantages compared to the ordinary steam cycle [5].

Various types of expanders were studied and employed in the literature for ORC applications to produce heat and power, including radial turbine expanders [6], screw expanders [7] and scroll expanders [8]. Different types of expanders were investigated by Qiu *et al.* [9], including scroll, screw and vane expanders. They reported that vane expanders and scroll expanders have a large potential to serve for heat production and power generation in micro-scale ORC applications due to their simplicity, high expansion ratios and cost-effectiveness. Lemort *et al.* [10] recommended the use of scroll expanders for low-temperature ORC applications due to their availability in the market, reduced number of moving parts and reliable operation mode, with the scroll compressors long successful record in refrigeration and air-conditioning applications. Different studies were carried out to model and optimize the performance of scroll expanders in various applications especially for ORC systems [11–14]. Peterson *et al.* [15] studied the performance of a regenerative ORC-based system for electricity generation using scroll expander and R-123 as a working fluid with a power output in the range of 187 to 256 W and ORC cycle efficiency of 7.2%. The recorded expander efficiency was in the range of 45 to 50% with an excessive fluid leakage across the expander during the unit operation. To solve such fluid leakage problems, Clemente *et al.* [16] recommended scroll expanders modified from air-conditioning system compressors as effective prime movers for small-scale ORC-based systems with low cost and reliable operation. Similar suggestion was presented by Brasz *et al.* [17] who studied the modification of a centrifugal compressor into a radial-in flow turbine. In addition, an experimental testing of a scroll expander modified from a compliant scroll compressor was investigated by Wang *et al.* [18]. Employing R-134 as ORC working fluid, the maximum reported expander isentropic efficiency attained was ~77% with 1 kW of electric power output.

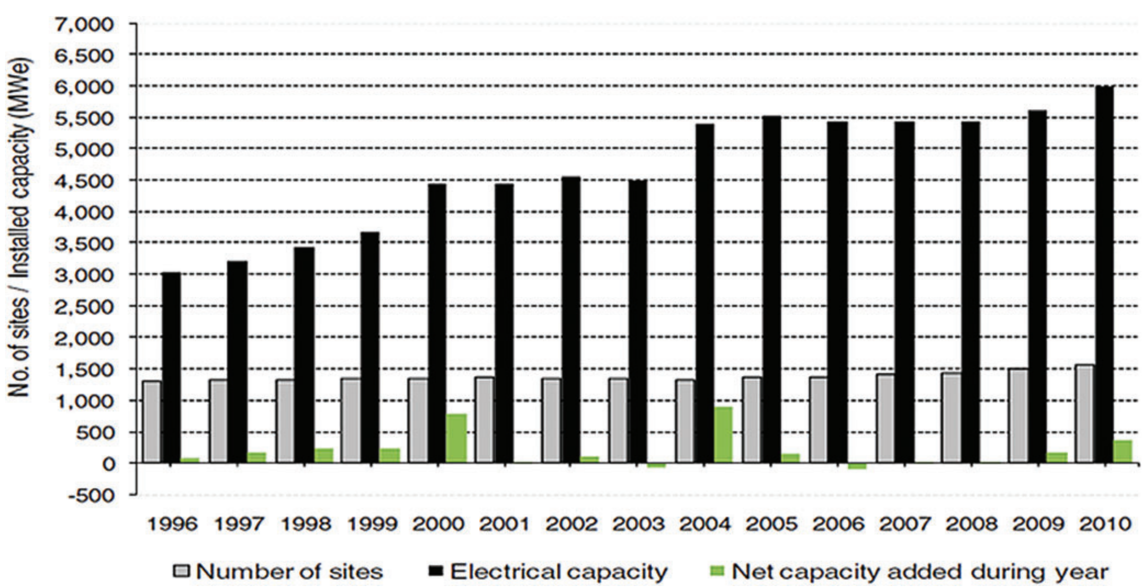

Figure 1. *Installed CHP capacity in the UK [3].*

Based on the background and review provided, it is shown that the majority of ORC expanders employed recently in ORC applications have suffered from high thermal losses, excessive working fluid leakage and low isentropic efficiency. In addition, micro-scale scroll expanders are still in the research and development stage with no commercial micro-scale scroll expanders available in the market and applicable for ORC applications retarding the development of commercial micro-scale ORC-based micro-CHP systems. In this work, a micro-scale ORC-based CHP system is theoretically and experimentally investigated to provide the thermal needs and part of the electrical demands for a residential application. The micro-CHP system is driven by renewable solar and biomass resources employing a new type modified scroll expander with environmentally friendly working fluid. Using the EES software, the micro-CHP system was modelled to simulate the thermodynamic behaviour of the ORC unit and predict the CHP system thermal and electrical performance. In addition, an experimental set-up was built to test the ORC-based CHP system performance under different operational conditions using HFE7100 fluid.

2 MATHEMATICAL FORMULATION

The ideal ORC cycle comprises four main components: evaporator, pump, turbine and condenser. Due to their durability, cost-effectiveness, high levels of reliability and simplicity, micro-CHP systems with ORC have received increasing attention for domestic and building applications. However, ORC-based micro-CHP systems are still in the phase of research and development, and many companies are working on developing such systems but currently no viable small-scale products are commercially available. Figure 2 shows the configuration of a regenerative Rankine cycle using a thermal recuperator to improve the performance of the conventional Rankine cycle. Water is heated by an external heat source (solar collector and biomass boiler) and is circulated to heat the ORC fluid at the evaporator level. The working fluid is pumped from lower to higher pressure and then heated to become a dry saturated vapour at the evaporator level using an external heat source. The superheated vapour undergoes an expansion through the turbine allowing electricity generation. Finally, the wet expanded vapour is cooled to saturated liquid in the condenser accompanied with heat rejection. This heat is absorbed by the condenser cooling water loop and can be utilized for beneficial thermal applications. The thermal recuperator is integrated between the low-pressure and high-pressure sides of the cycle to utilize additional heat from the working vapour at the expander outlet in order to pre-heat the ORC working fluid pumped to the evaporator.

Taking into account the conservation of mass for the working fluid employed in the cycle and applying the first law of thermodynamics for the ideal Rankine cycle, the work of the pump is given by:

$$W_{\mathrm{P}} = \dot{m} \times (h_2 - h_1) \tag{1}$$

The ideal work output provided by the expander is given by:

$$W_{\mathrm{Ex}} = \dot{m} \times (h_4 - h_5) \tag{2}$$

where h is the enthalpy of the working fluid (J/kg), and $\dot{m}$ is the working fluid mass flow rate (kg/s). The ORC net work can be expressed as follows:

$$W_{\mathrm{net}} = \dot{m} \times [(h_4 - h_5) - (h_2 - h_1)] \tag{3}$$

On the other side, the external heat input at the evaporator can be given by:

$$Q_{\mathrm{in}} = \dot{m} \times (h_4 - h_3) \tag{4}$$

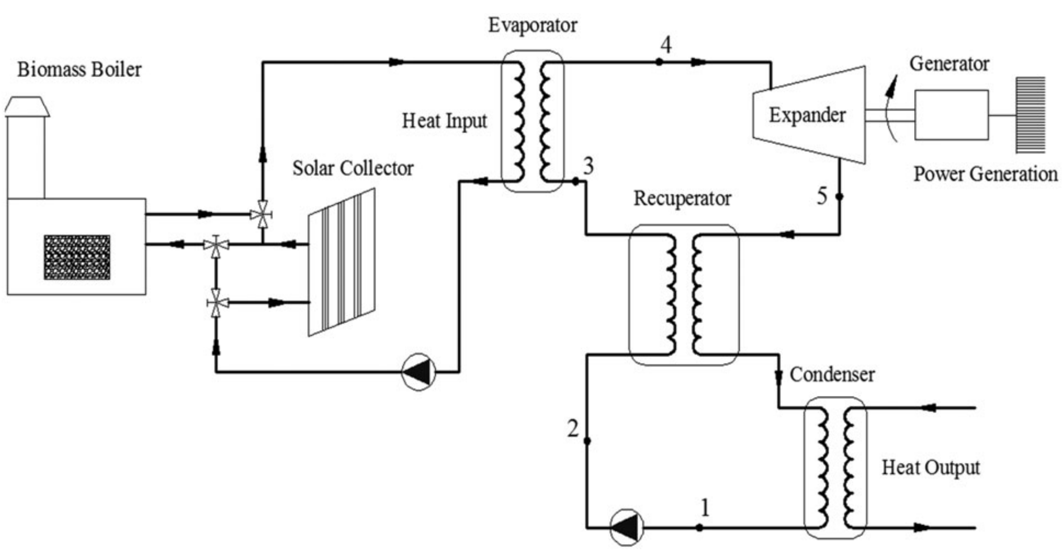

Figure 2. *Configuration of a regenerative Rankine cycle with a thermal recuperator.*

The overall ORC thermal efficiency is the ratio of the net work over the total input external heat and can be given by:

$$\eta_{ORC} = \frac{W_{net}}{Q_{in}} \quad (5)$$

The mechanical efficiency of the expander is defined as the electric power output W_{Ele} divided by the expander actual work output:

$$\eta_{mech} = \frac{W_{Ele}}{\dot{m} \times (h_4 - h_5)} \quad (6)$$

The expander isentropic efficiency is defined as the ratio of the actual work produced by the expander over the ideal work and can be given by the following equation:

$$\eta_{is} = \frac{(h_4 - h_5)}{(h_4 - h_{5'})} \quad (7)$$

where $h_{5'}$ is the isentropic enthalpy of the working fluid at the expander outlet.

The useful heat absorbed by the condenser water can be given by

$$Q_{cond} = \dot{m}_{cond} \times (h_{cond\_out} - h_{cond\_in}) \quad (8)$$

where $\dot{m}_{cond}$ is the mass flow rate (kg/s) of the condenser cooling water. The total amount of solar energy available at the solar collector is expressed as follows:

$$Q_{Sol} = I_{Sol} \times A_{col} \quad (9)$$

where I_{Sol} is the total solar radiation flux (W/m^2) available at the collector and A_{col} is collector aperture area (m^2). The heat of combustion provided by the biomass boiler is given in terms of the rate of consumption of the biomass pellets $\dot{m}_{Bio}$ and lower heating value (LHV) of the wood pellets:

$$Q_{Bio} = \dot{m}_{Bio} \times \mathrm{LHV} \quad (10)$$

Thus, the ORC-based micro-CHP system electrical and thermal efficiencies are given by the following equations, respectively:

$$\eta_{Ele} = \frac{W_{out}}{Q_{Sol} + Q_{Bio}} \quad (11)$$

$$\eta_{Th} = \frac{Q_{cond}}{Q_{Sol} + Q_{Bio}} \quad (12)$$

3 PARAMETRIC STUDY

Using the EES software, a numerical simulation model was developed to predict the thermal and electrical performance of the ORC-based CHP system. HFE7100 is considered as an environmentally friendly organic working fluid in the Rankine cycle. The working fluid is a mixture of two isomeric chemicals: methoxynonafluoroisobutane and methoxynonafluorobutane, forming a single chemical entity, due to their similar boiling points and inseparable nature listed in the Australian Inventory of Chemical Substances. HFE7100 is clear, colourless, low-odour and non-flammable fluid with zero ozone depletion potential and very low global warming potential. With a boiling point of 60.04°C and a critical temperature of 195.3°C, HFE7100 is suitable for micro-CHP systems providing useful heat for building applications in the form of under-floor heating or domestic hot water.

Employing the model developed in the EES software, a parametric study of the ORC-CHP unit was carried out to investigate the effect of the expander inlet temperature (T_{Ex_in}) and the expander inlet pressure (P_{Ex_in}) on the thermal and electrical performance of the overall ORC-CHP system. The environmentally friendly HFE7100 was considered as a working fluid in the Rankine cycle, and a biomass boiler is assumed to provide the heating input to evaporate the ORC fluid and run the system. The ORC parameters in the reference case have the following values: HFE7100 mass flow rate of 0.2 kg/s, condenser water temperature of 0.1 kg/s, expander inlet temperature and pressure of 130°C and 500 kPa, and pump inlet temperature and pressure of 20°C and 60 kPa. In addition, the expander efficiency was assumed to be 0.85 throughout the simulations with a biomass boiler heating efficiency of 0.9.

Table 1 presents the effect of the HFE7100 temperature at the expander inlet on the ORC various output parameters. It is shown that the ORC efficiency, electrical efficiency and thermal efficiency are inversely proportional to the increase in the expander inlet temperature. The ORC efficiency decreases from 10.87 to 10.21% with the increase in the expander inlet temperature from 120 to 150°C. However, the increase in the HFE7100 inlet temperature allows an increase in the temperature of the condenser water in addition to an increase in both the electrical power produced and the useful heat delivered.

In addition, Table 2 presents the effect of the HFE7100 pressure at the expander inlet on the ORC-CHP performance. It is shown that the ORC efficiency and electrical efficiency are proportional to the increase in the expander inlet pressure, where the thermal efficiency decreases as the pressure increases. Increasing the expander inlet pressure from 300 to 550 kPa,

Table 1. *Effect of expander inlet temperature on the overall CHP performance.*

T_{Ex_in} (°C)	η_{ORC} (%)	η_{Ele} (%)	η_{Th} (%)	T_{cond_out} (°C)	W_{Ele} (kW)	Q_{out} (kW)
120	10.87	9.866	65.91	83.33	3.96	26.5
125	10.75	9.749	67.31	86.59	4.03	27.87
130	10.64	9.636	65.9	87.1	4.10	28.08
135	10.53	9.526	64.56	87.6	4.17	28.29
140	10.42	9.418	63.27	88.09	4.24	28.5
145	10.31	9.314	62.03	88.57	4.31	28.7
150	10.21	9.213	60.84	89.04	4.37	28.9

Table 2. *Effect of expander inlet pressure on the overall CHP performance.*

P_{Ex_in} (kPa)	η_{ORC} (%)	η_{Ele} (%)	η_{Th} (%)	T_{cond_out} (°C)	W_{Ele} (kW)	Q_{out} (kW)
300	8.152	7.45	65.96	88.29	3.22	28.59
350	8.921	8.122	65.92	87.98	3.50	28.45
400	9.575	8.695	65.9	87.68	3.73	28.33
450	10.14	9.195	65.89	87.39	3.93	28.21
500	10.64	9.636	65.9	87.1	4.10	28.08
550	11.08	10.03	65.91	86.81	4.25	27.96
600	11.48	10.38	63.4	83.97	4.38	26.77

Table 3. *Effect of the solar energy share on the overall CHP performance.*

Total heat input (kW)	Solar energy share (%)	Solar collector area (m^2)	CHP efficiency (%)
24.23	100	36.6	69.7
24.23	80	29.6	72.3
24.23	60	22.2	75.3
24.23	50	18.5	76.9
24.23	40	14.8	79.3
24.23	20	7.4	82.2
24.23	0	0	86.7

keeping other parameters fixed, is accompanied by an increase in the ORC efficiency from 8.15 to ~11.5%. Based on the simulation results, the useful heat produced by the CHP unit is directly proportional to the expander inlet pressure, where the electric power produced increases with the increase in the pressure. This is mainly due to the increase in the pressure difference across the ORC expander.

Using a biomass–solar combined energy source to provide a heat input of 24.23 kW to the ORC-CHP system, Table 3 presents the effect of the solar energy share on the solar collector area required and on the overall CHP efficiency. The Thermomax DF100 evacuated tube solar collector was utilized in the simulation model to heat the water in the heating loop [19]. It is shown that the overall CHP efficiency has decreased from ~86 to ~69% with the increase in the solar energy share in the heat input from 0 to 100%. Based on the model simulations, a solar collector area of 36.6 m^2 is required to provide the whole ORC-CHP heat input needs. In addition, Figure 3 presents the effect of the biomass energy share on the rate of consumption of wood pellets and on the system electrical and thermal performance employing wood pellets of 4.8 kWh/kg calorific value. It is shown that the CHP electrical and thermal efficiencies are directly proportional to the biomass energy share in the heating input. Burning of 5.61 kg/h of wood pellets in the biomass boiler can provide all the heating input required to drive the CHP system considered. Based on the simulation results, it is concluded that the larger the biomass boiler share in the heating input the higher the performance of the ORC-CHP unit.

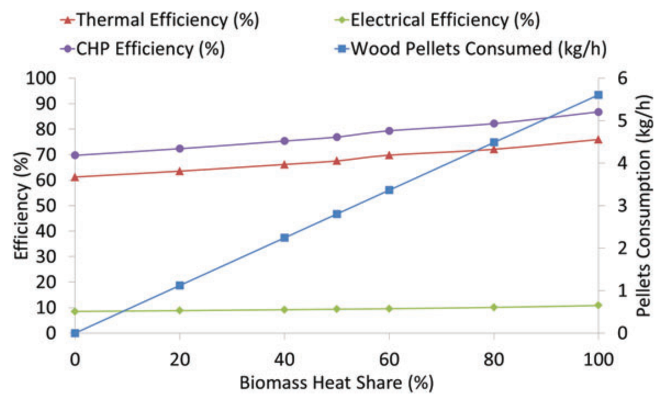

Figure 3. *Effect of the biomass energy share on the overall CHP performance.*

4 EXPERIMENTAL SET-UP

An innovative expander modified from an air-conditioning scroll compressor was considered in this study to test and assess the feasibility of using such new-type expanders in low-temperature ORC applications. SHS-33B4150 scroll compressor from Sanden was investigated in this work. The scroll compressor was introduced recently as air compressor being mass produced in low-cost to fulfil air-conditioning needs in the Mercedes S400 electric hybrid cars [20]. The semi-hermetic scroll compressor comprises a DC brushless motor providing low operational pressures and minimum clearance volume effect. The compressor compact configuration and design allows a smooth and clean operation with less working fluid leakage and low noise levels. In addition, the permanent magnetic motors and the integrated drive electronics are highly efficient offering the possibility of efficient electricity generation if the compressor is modified to work as an expander. The internal discharge valve of the expander was removed, and the integrated inverter was disconnected allowing the modification of the compressor to work as a scroll expander. HFE7100 was utilized as a working fluid to eliminate any refrigerant environmental negative impacts in addition to its physical and environmental advantages.

The experimental CHP set-up overall configuration is shown in Figure 4 with the main system components. As shown in the figure, the system consists of the main organic Rankine loop, hot water loop and condenser water loop. A biomass boiler, as a renewable-based heating source, was utilized to supply hot water and provide heat input at the level of the evaporator to heat and evaporate the HFE7100 working fluid in the ORC unit. In addition to the evaporator, a superheater with a plate heat exchanger was employed to provide additional heating to the ORC cycle and produce superheated vapour at the inlet of the scroll expander. Thus, superheated vapour is expanded at the expander level allowing electric power generation. Through the recuperator, the hot vapour at the expander exhaust is utilized to pre-heat the HFE7100 fluid pumped to the evaporator. Then, the expanded vapour is cooled to saturated liquid at the condenser level where heat is absorbed by the cooling water loop and useful heat is produced. A sight glass is introduced in the superheater–expander line to monitor the quality of the working fluid introduced to the expander. In addition, a fluid reservoir is included after the superheater to stabilize the working fluid pressure and inhibit any fluid condensate to be carried with the vapour to the expander inlet. A receiver vessel was employed before the pump in the Rankine cycle as a store for the working fluid with a liquid-level indicator to monitor the HFE7100 level in addition to a valve integrated for working fluid top up.

As shown in Figure 5a, the scroll expander was integrated in the experimental unit and placed at the highest possible position in the rig with the scroll axis in a vertical position. This will facilitate the vertical downward flow of the vapour with no additional bending in the pipe line between the expander and the evaporator on one side and the expander and the recuperator on the other. SWEP heat exchangers used for the condenser, evaporator and recuperator are shown in Figure 5b. The connection copper pipes in addition to the heat exchangers employed at different levels in the unit were tightly insulated to enhance the overall thermal performance of the CHP system minimizing the thermal losses. The environmentally friendly HFE7100 was used as an organic working fluid in the Rankine cycle, instead of conventional hydrofluorocarbon and hydrochlorofluorocarbon fluids, which have negative impacts on the environment. In addition, a 50-kW Ashwell wood pellet biomass boiler was employed as an external heat input source to provide hot water at the CHP system evaporator and superheater levels in order to evaporate

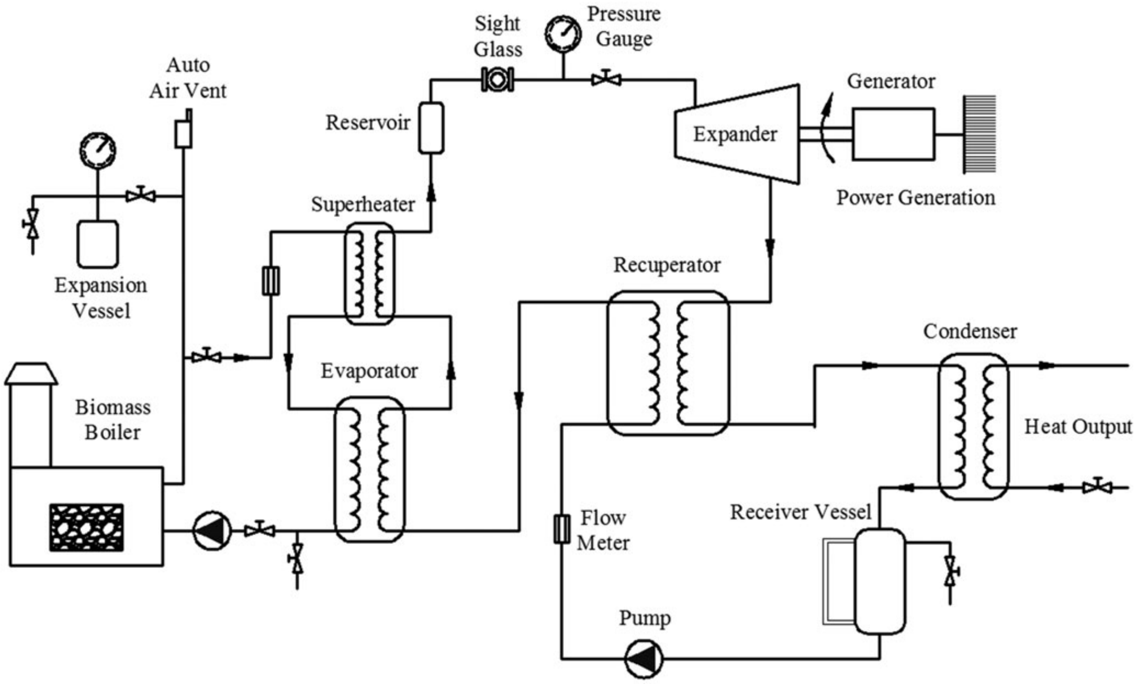

Figure 4. *Overall configuration of ORC-CHP experimental system.*

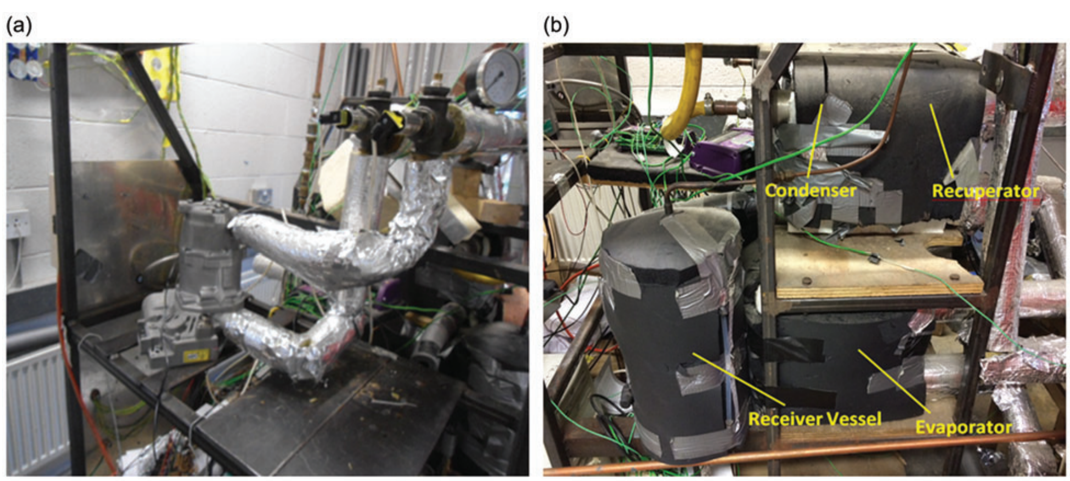

Figure 5. *Scroll expander fitted in the experimental unit (**a**), experimental rig main components (**b**).*

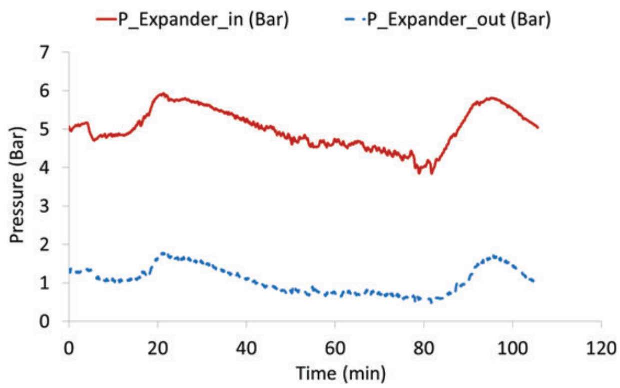

Figure 6. *HFE7100 pressure at the expander inlet and outlet.*

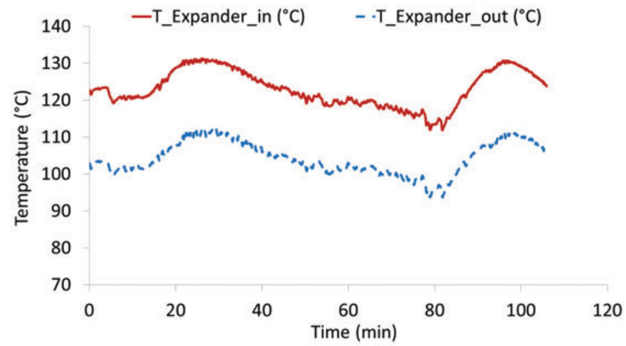

Figure 7. *HFE7100 temperature at the expander inlet and outlet.*

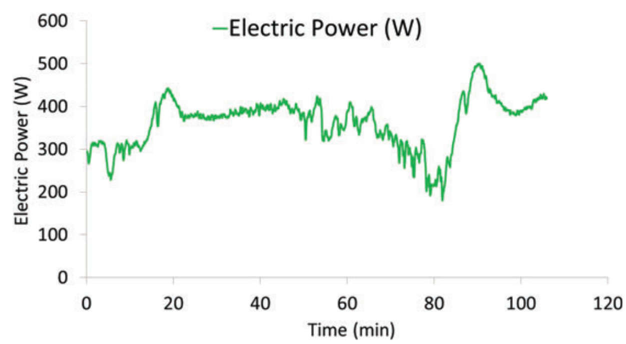

Figure 8. *Expander electric power generated.*

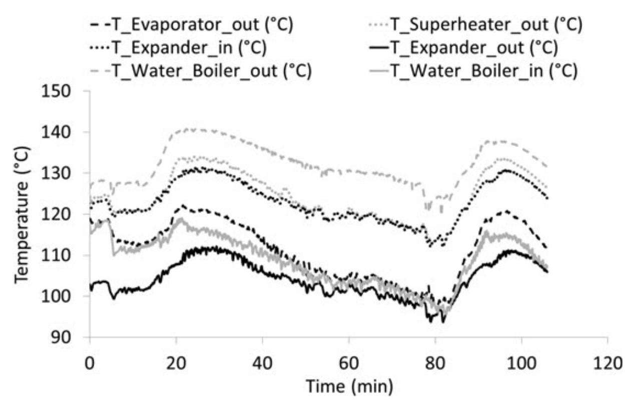

Figure 9. *HFE7100 and water temperature variation.*

the working fluid and drive the ORC-based CHP system. An integrated digital control panel is used to set the biomass boiler operational parameters including the set operation temperature, heating capacity and wood pellets feed. The biomass boiler combustion is mainly controlled by a primary air supply from the furnace bed walls in addition to a secondary air from the vent tubes around the flame. The boiler hopper was loaded with biomass wood pellets. Then, the water circulation pump and the wood pellet auger screw conveyor were switched on to launch the heating process allowing a continuous and stable heat input to the ORC unit. A bank of halogen lamps was employed in the system to serve as an electric load. Different recording and monitoring devices were used and installed in the rig including pressure transducers, K-type thermocouples, water and refrigerant flow meters and electric DK current transducer in order to record the electrical and thermal parameters throughout the ORC-CHP unit. All the recording devices were connected to a Datataker DT 80 data logger, which was directly linked to a computer for instant data logging and monitoring of the system operational parameters.

Figure 6 shows the variation in the HFE7100 pressure at the inlet and outlet of the expander during an experimental session employing 0.047 kg/s as HFE7100 mass flow rate. It is shown that the HFE7100 pressure at the expander inlet has ranged between 3.83 and 5.95 bar with a pressure difference across the expander in the range of 1.75 to 4.52 bar. In addition, Figure 7 presents the variation in the HFE7100 temperature at the expander inlet and outlet. The temperature at the expander inlet has ranged between 111.9 and 131.3°C. The average temperature of the working fluid at the exhaust of the expander was ~104.5°C with a maximum exhaust temperature of 112.3°C.

Figure 8 shows the variation in the electric power generated by the expander throughout the experimental session with 0.047 kg/s as working fluid mass flow rate. The maximum electric power delivered by the modified scroll expander was ~500 W under a pressure ratio of 4.6 across the expander with a pressure differential of 4.3 bar. It is noted that during the experimental testing, the scroll expander exhibits a quiet and smooth operation with no working fluid leakage.

Employing 0.047 kg/s as HFE mass flow rate and 0.13 kg/s as heating water mass flow rate, Figure 9 presents the variation in the water supply and return temperatures across the biomass boiler in addition to the HFE7100 temperature at different points in the Rankine cycle. The boiler water supply temperature varies in the range of 119 to 140°C with an average water return temperature of ~108.6°C at a boiler set temperature of 135°C. In addition, the HFE7100 temperature at the superheater outlet ranges between 113 and 134°C, indicating good heat exchange efficiency between the biomass boiler heating water and the organic working fluid at the level of the superheater. The HFE7100 average temperature at the evaporator outlet is ~111.4°C with a working fluid temperature between 93 and 113°C at the expander exhaust.

Figure 10 shows the HFE7100 temperature difference across the expander in addition to the water temperature difference across

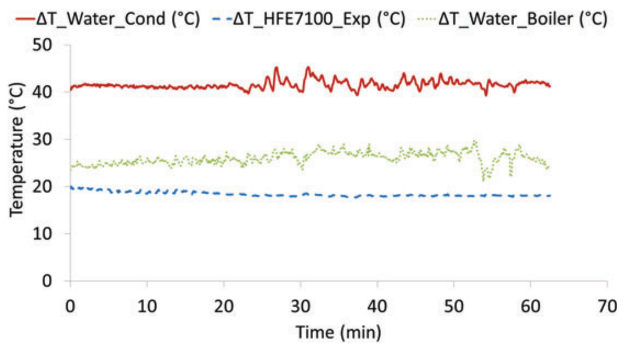

Figure 10. *Water temperature difference across the condenser and biomass boiler and HFE7100 temperature difference across the expander.*

the biomass boiler and condenser. It is shown that the average temperature difference across the expander is ~18.8°C. With an average water supply temperature of 7.7°C at the condenser level and employing 0.0542 kg/s as cooling water mass flow rate, the average water temperature difference across the condenser is ~41.5°C with a maximum water temperature of 53°C at the condenser outlet. In addition, the average heating water temperature difference across the biomass boiler is ~25.4°C with 0.13 kg/s of mass flow rate.

The experimental data recorded by different measurement devices employed during the experimental sessions carried out were introduced to the numerical simulation model developed in the EES software to estimate the micro-scale ORC-based CHP system overall generation capacities and operation efficiency. With 0.047 kg/s of HFE7100 working fluid mass flow rate, 0.13 kg/s of heating water mass flow rate and 0.0542 kg/s of condenser water mass flow rate, the maximum electric power generation by the modified scroll expander is ~500 W with a recorded voltage of 43 V across the halogen lamps bank load. At this maximum point of electric power generation, the supply and return heating water temperature at the biomass boiler level are ~135 and 113°C, respectively. The temperature of the HFE7100 supply to the expander is 126.5°C with 5.5 bar superheated vapour pressure. In addition to the electric power generated at the expander level, the ORC-based CHP is capable of producing ~9.6 kW of useful heat at the condenser level with a water output temperature of ~50°C. The estimated expander mechanical efficiency at the point of maximum electric power generation is ~81% with an isentropic efficiency of 75% and an ORC efficiency of 5.7%. The micro-CHP system thermal efficiency is ~78% with an overall efficiency in the range of 83.1%.

5 CONCLUSION

Micro-scale ORC expanders studied and investigated recently have suffered from key problems including high thermal losses, low isentropic efficiency and excessive working fluid leakage. Such problems have retarded the development and promotion of commercial micro-scale ORC-based CHP units. To address these problems and due to the large potential possessed by ORC units in the field of heat and power production, a micro-scale ORC-based CHP system driven by solar-biomass renewable energy resources is studied and investigated in this work to provide the thermal and part of the electrical demands for residential and building applications. An innovative scroll expander modified from an automotive air-conditioning scroll compressor is employed as the prime mover for the considered micro-scale ORC-based CHP system. EES software was used to simulate the thermal and electrical performance of the CHP system investigating the effect of different operational parameters on the overall CHP performance. Moreover, an experimental set-up was built for the micro-scale ORC-CHP system to test the performance under different conditions employing HFE7100 as an environmentally friendly ORC working fluid and a 50-kW biomass boiler as a heating source. At an HFE7100 pressure ratio of 4.6 across the expander, the CHP system has generated a maximum of 500 W of electric power and ~9.6 kW of useful heat at the condenser level with an ORC efficiency of 5.7% and overall CHP efficiency of 83%. The scroll expander has exhibited a smooth and quiet operation with no working fluid leakage and an isentropic efficiency exceeding 80% at the peak operating points. This can open the door for such types of expanders to be further investigated and developed to serve different ORC micro- and small-scale applications including CHP units.

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